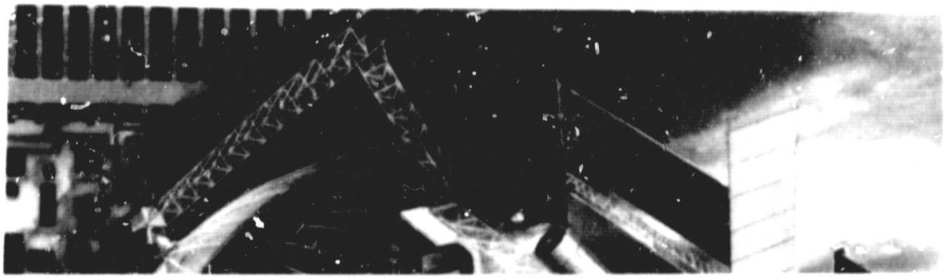
Final Report Volume IV
Tehcnology Advancement
Program Plan
D180-27487-4

Advanced Platform Systems Technology Study



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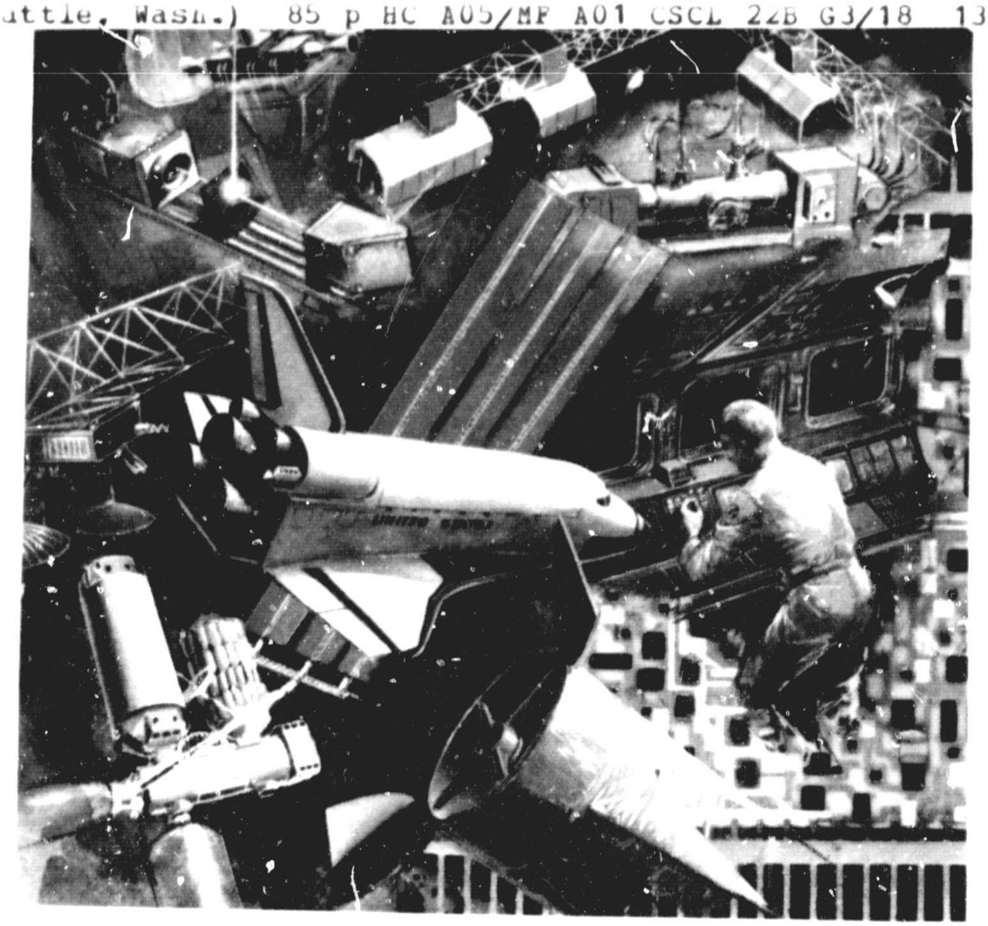

April 1983

BOEING

ADVANCED PLATFORM SYSTEMS TECHNOLOGY STUDY

Final Report

VOLUME IV

TECHNOLOGY ADVANCEMENT PROGRAM PLAN

D180-27487-4

Conducted for NASA Marshall Space Flight Center

Under Contract Number NAS8-34893

April 1983

Boeing Aerospace Company

Spectra Research Systems

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LIST OF ACRONYMS AND ABBREVIATIONS

ARC	Ames Research Center
ATP	Authority to Proceed
CDR	Critical Design Review
CRT	Cathode Ray Tube
dB	Decibels
DISCO	Distributed Star Coupled
DOD	Department of Defense
EC/LSS	Environmental Control-Life Support System
EMI	Electro-Magnetic Interference
EMU	Extra-Vehicular Mobility Unit
ETC	Etcetera
EVA	Extra Vehicular Activity
FDS	Frequency Division Multiplexing
F/O	Fiber Optic
ft	Feet
FY	Fiscal Year
GEO	Geostationary Orbit
GBPS	Giga bits per second
GSFC	Goddard Space Flight Center
HM	Habitat Module
H/O	Hydrogen-Oxygen
hr	Hour
Hz	Hertz
IAC	Integrated Analysis Capability
IAF	International Aeronautical Federation
IBM	International Business Machines
IC	Integrated Circuits
IEEE	Institute of Electrical, Electronics Engineers

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

ILD	Injection Laser Diode
IR	Infrared
ISO/OSI	International Standards Organization/Open System Interconnect
ITT	International Telephone and Telegraph
IVA	Intervehicular Activity
JPL	Jet Propulsion Laboratories
JSC	Johnson Space Center
K	Thousand
KBPS	Kilo bits per second
KG	Kilograms
km	Kilometer
kW	Kilowatts
kWHR	Kilowatt hours
LAN	Local Area Network
LaRC	Langley Research Center
lb	Pound
LED	Light Emitting Diode
LEO	Low Earth Orbit
LISP	List Processor
LM	Logistics Module
LOX	Liquid Oxygen
LRU	Line Replaceable Units
LSI	Large Scale Integration
LSS	Life-support System
LV/LH	Local Vertical/Local Horizontal
M	Million
MBPS	Millions of bits per second
MHz	Mega Hertz
MIPS	Millions of iterations per second
MMS	Multimission Modular Spacecraft
MPS	Meters per second

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

MSFC	Marshall Space Flight Center
MSI	Medium Scale Integration
MTBF	Mean Time Before Failure
NASA	National Aeronautics and Space Administration
NIM	Network Interface Module
nm	Nautical miles
NMS	Newton-meter-seconds
NOS	Network Operating System
OAO	Orbiting Astronomical Observatory
OPERA	Orbital Payload Environmental Radiation Analyzer
OTV	Orbital Transfer Vehicle
PCS	Plastic Clad Silica
PDR	Preliminary Design Review
PIN	Positive Intrinsic Negative
psia	Pounds Per Square Inch Absolute
RCA	Radio Corporation of America
RCS	Reaction Control System
RFI	Radio Frequency Interference
RPS	Revolutions per second
SAR	Synthetic Aperature Radar
SADMP	Science and Applications Manual Space Platform
SASP	Science and Applications Space Platform
sec	Seconds
SOC	Space Operations Center
SIF	Systems Integration Facility
SRS	Spectra Research Systems
SSI	Small Scale Integration
STS	Space Transportation System
TCS	Thermal Control System
TDRSS	Tracking Data Relay Satellite System

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

TOC	Total Organic Carbon
TV	Television
ULSI	Ultra Large Scale Integration
VAX	Virtual address extension
VHSIC	Very High Speed Integration Circuit
VLSI	Very Large Scale Integration
VOL	Volume
WDM	Wavelength Division Multiplexing
WQM	Water Quality Monitor

FOREWORD

The Advanced Platform Systems Technology Study (Contract NAS8-34893) was initiated in July 1982 and completed in April 1983. The study was conducted for the National Aeronautics and Space Administration, Marshall Space Flight Center, by the Boeing Aerospace Company with Spectra Research Systems as a subcontractor. The study final eport is documented in four volumes.

D180-27487-1	Vol. I	Executive Summary
D180-27487-2	Vol. II	Trade Study and Technology Selection Technical Report
D180-27487-3	Vol. III	Support Data
D180-27487-4	Vol. IV	Technology Advancement Program Plan

Mr. Robert F. Nixon was the contracting officer's representative and study technical manager for the Marshall Space Flight Center. Dr. Richard L. Olson was the Boeing study manager and Mr. Rodney Bradford managed the Spectra Research Systems effort.

1.0 INTRODUCTION

This volume of the Final Report for the Advanced Platform Systems Technology study provides the Technology Advancement Program Plans for the critical or high priority technology items identified in the system trade studies (see Volume II). The overall study effort proceeded from the identification of 106 technology topics to the selection of 5 for detail trade studies. The technical issues and options were evaluated through the trade process. Finally, individual consideration was given to costs and benefits for specific technologies identified for advancement.

Eight priority technology items were identified for advancement and are reported in Volume II together with the rationale and justification for their selection. The Program effort was divided into three primary tasks which include: Task 1 - Trade Studies, Task 2 - Trade Study Comparison/Technology Selection, and Task 3 - Technology Definition. This volume reports on the results of Task 3. The primary objective of Task 3 was to provide implementation plans for each technology item identified in task 2. The plans include technical approaches, resources costs and schedules keyed to a platform program development schedule with system design go ahead in 1986 - 1987. The technology plans were developed by synthesizing and integrating the system trade study results, cost and schedule estimates, and comparative benefit assessments, along with resource requirement estimates for the selected technologies.

The flow diagram of figure 1.0-1 shows an overview of the major technology definition tasks and subtasks along with their interfaces and interrelationships. Although not specifically indicated in the diagram, iterations were required at many steps to finalize the results. The development of the integrated technology advancement plan was initiated by using the results of the previous two tasks in the study, i.e., the trade studies and the preliminary cost and schedule estimates for the selected technologies. Descriptions, for the development of each viable technology advancement was drawn from the trade studies. Additionally, a logic flow diagram depicting the steps in developing each technology element was developed along with descriptions for each of the major elements. Next, major elements of the logic flow diagrams were time phased, and that allowed the definition of a technology development schedule that was consistent with the space station program schedule when possible. Schedules show the major milestones including tests required as described in the logic flow diagrams.

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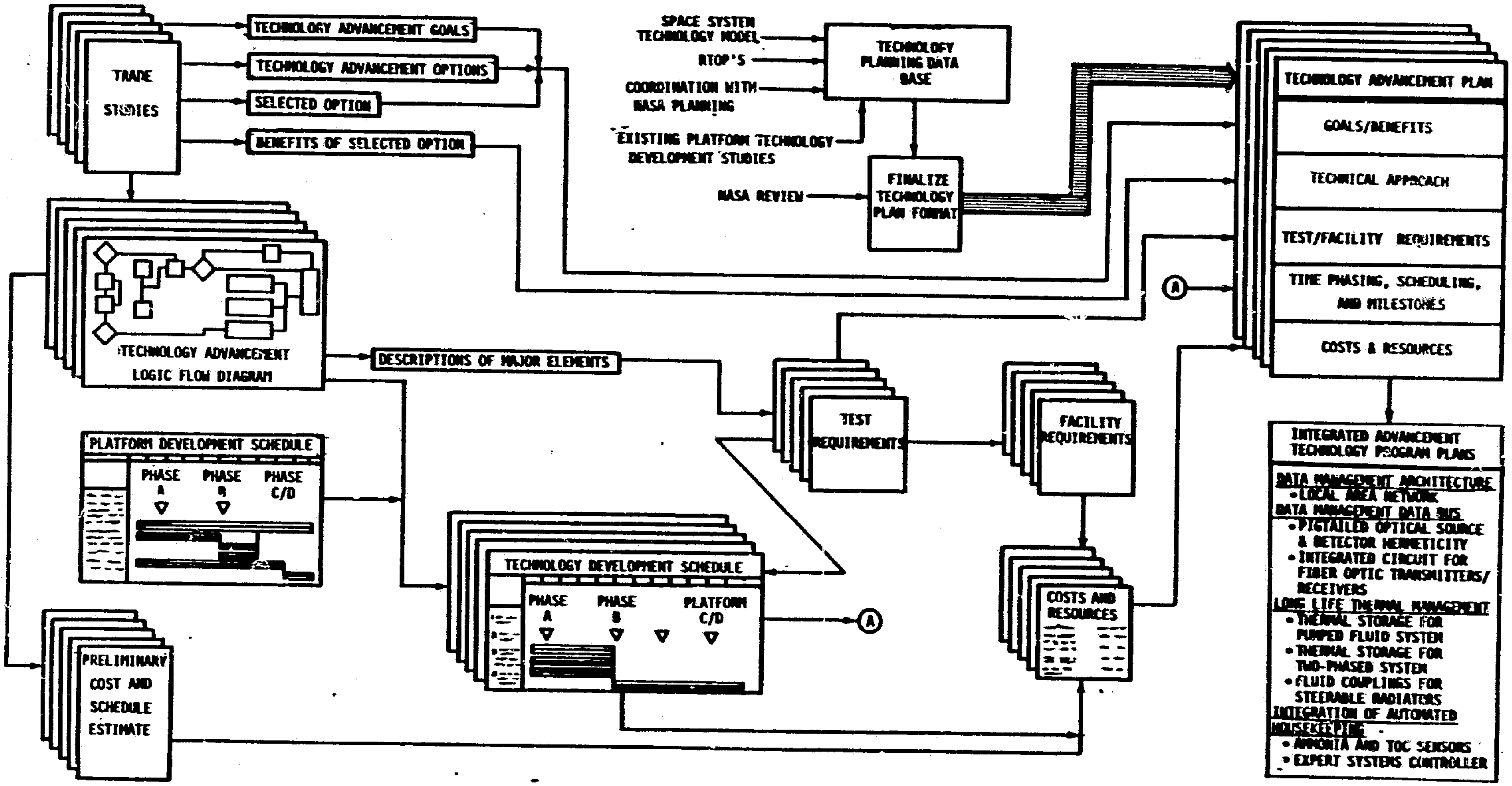

Figure 1.0-1 Task 3 Flow Diagram

Cost and resource estimates were primarily based on the RCA PRICE hardware development cost modeling program and past experience in similar technology development programs. The result produced by this task is an advancement plan for each selected technology which reflects related technology status and planning within NASA and Industry. Consequently, an integrated technology advancement plan has been developed from the set of individual advancement plans and is provided in this volume.

Advancement program plans were developed for the following areas:

(1) Data Management Data Bus
(2) Data Management Architecture
(3) Integration of Automated Housekeeping
(4) Long Life Thermal Management System

The plans are similar in format for each technology area and specific technology items within the areas. Each plan contains information on: Technical Approach, Facility Requirements and Candidate Facilities, Development Schedules, and Resource Requirements Estimates.

To summarize the results of this task, the advancements are planned to be accomplished on schedules to support a 1990's space station with one exception—the development of integrated circuits for fiber optics transmitters and receivers. Section 2.3.4 discusses the unique scheduling considerations for this exception. The planning here is based on an early 1984 start on the programs laid out in this volume and requires vigorous, but not "crash" programmatic emphasis. Other qualifiers on the technology readiness represented in these plans involve the local area network development for the data management system architecture and the expert system controller development. The local area network development has two phases. The first develops the technology to the breadboard level, which is sufficient to support the start of space station design activities. The second phase which can take place during the initial stages of space station detailed design would produce the required network hardware. This should be sufficient to suport final design stages of the space station program. In the case of the expert system controller, this development is aimed at evolutionary space station designs and is predicated on the use of initial space station without such a controller in order to gain operational experience.

An integrated summary of the schedules and time phased resource requirements for the technology development plans is given in figure 1.0-2. Total resource requirements for this integrated development of high leverage technologies is approximately $85.4 million. A large portion of this ($64 million) is required by the local area network development alone. The plans also show that existing facilities are sufficient to support the advancement program.

RANKING	ADVANCEMENT ITEM DEVELOPMENT	1	2	3	4	5	6	7	
1	INTEGRATED CIRCUIT TRANSMITTER/RECEIVER	.095	1.5	1.2	1.2	1.3	1.3	.675 ▽	7.27
2	EXPERT SYSTEM FOR INTEGRATED AUTOMATED HOUSEKEEPING	.5	1.1	2.2	1.7	1.75	1.75 ▽		9.
3	DATA ARCHITECTURE LOCAL AREA NETWORK	3	5.3	6.7 ◊	14.3	15.8	18.9 ▽		64.
4	AMMONIA OR TOC SENSOR SENSOR	.12	.2	.44	.24 ▽				1.
5	THERMAL STORAGE FOR PUMPED FLUID SYSTEM	.15	.25	.3	▽ .1				.8
5	THERMAL STORAGE FOR TWO-PHASED SYSTEM	.305	.4	.395	▽ .1				1.2
5	STEERABLE RADIATOR FLUID COUPLING	.3	.4	.5	▽ .4				1.6
6	PIGTAILED HERMETIC OPTICAL SOURCE AND DETECTOR	.075	.205	.220 ▽					.5
	TOTAL	4.5	9.3	11.9	18	19	22	7	85.4M

▽ COMPLETE QUAL TESTING ◊ COMPLETE BRASSBOARD CONCEPT TESTING

Figure 1.0-2 Technology Advancement Items: Ranking by Schedule Urgency

2.0 DATA MANAGEMENT DATA BUS TECHNOLOGY ADVANCEMENT PLAN

2.1 INTRODUCTION

The development of emerging new technology in data network design using optical fiber components has been identified in Volume II as having significant benefits in terms of weight and data network performance and forms the basis for the advancement planning given in this section.

The primary development goal of the planning is to provide an efficient, reliable fiber optic data network for the early manned space station that will accommodate evolutionary growth without requiring extensive modifications. This requires technology advancement in critical areas to decrease the signal losses associated with currently available fiber optics source and detector coupling techniques and to provide high data rate integrated circuit optical transmitters and receivers. The capabilities of fiber optic components will influence the speed, reliability, and data handling capacity of the entire data management network.

The near term and evolutionary station configurations summarized in figure 2.0-1 represent the goals the data network must meet. As a result of system trades performed as task 1 and task 2 of this study, two fiber optics bus technology items have been selected as offering significant benefits in cost and performance and require NASA development support. These are:

(1) Pigtailed Optical Source and Detector Hermeticity, and
(2) High Bandwith/Data Rate Integrated Circuit Transmitters and Receivers.

These do not represent a total delineation of the optical fiber technology necessary to support a space station design, but they do represent those items of fiber optics data network technology that are critical since they might not otherwise be developed in time for an FY87 new start on the space station program. Since the overall system design is not defined to the level necessary to specify performance requirements for the network components (i.e., transmitters and receivers) this development plan must be coordinated with the data management architecture technology development plan. Also, there are several studies involving data systems, space station planning, and other topics whose results might impact data network design for the Space Station. Table 2.0-1 is an illustrative listing of research and technology objectives and plans submitted last year by the major NASA centers that would fall into this category.

TABLE 2.0-1. FY82 RTOP SUBMISSIONS RELATED TO TECHNOLOGY APPLICABLE TO SPACE STATION FIBER OPTIC DATA BUS TECHNOLOGY DEVELOPMENT

CENTER	TITLE	OBJECTIVES	BENEFITS
LaRC	NASA end-to-end data system: information adaptive system and on-board data storage.	o Develop and demonstrate an on-board spacecraft data system which adaptively controls and pro cesses high speed, multi-spectral sensor data.	o Simplication of sensor data reduction resulting in greater utility of data. Reduction in requirement for ground processing. Should reduce the possible number of single point failures.
GSFC	NASA end-to-end data system (needs): Phase 2.	o Develop alternative space platform data system concepts. o Develop high speed data handling system architecture.	o Improved data handlng capabilities.
GSFC	Microwave/optical components and techniques.	o Development of high data rate modulator/ exciters, high power amplifiers, low noise receivers, and other advanced data transfer system concepts.	o High data rates, simultaneous multiple links, and reliable long life operation.

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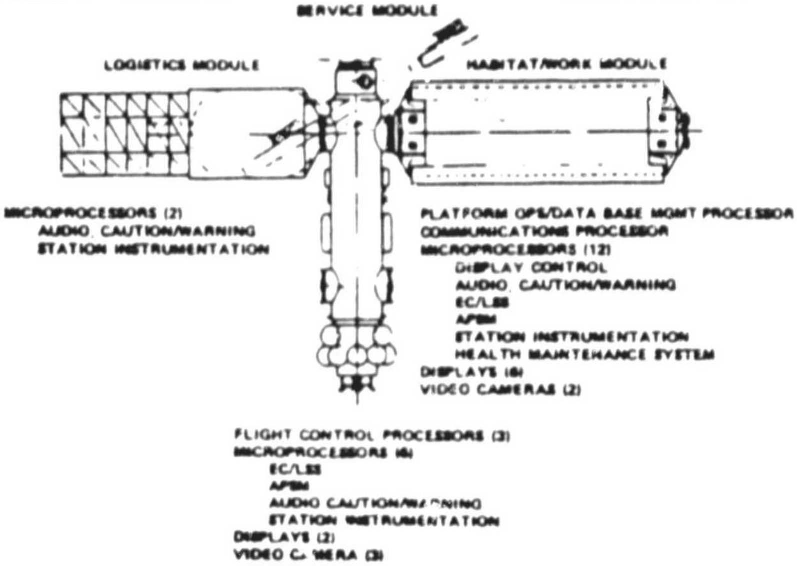
BASIC MANNED SPACE STATION</td><td>
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<tr><td>EVOLUTIONARY

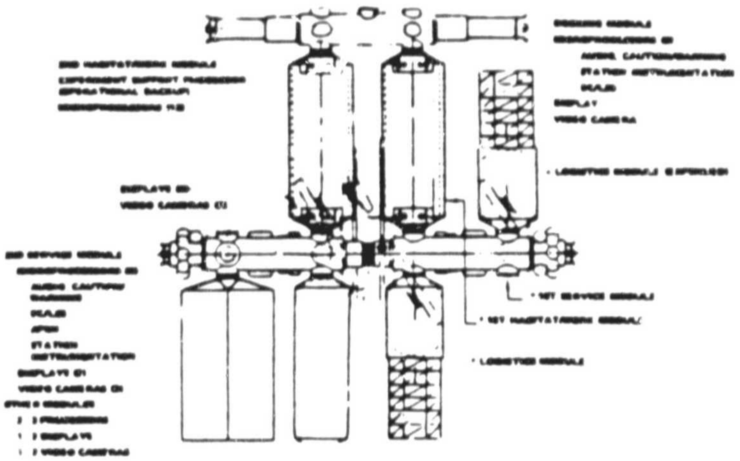
SECOND ORDER SPACE STATION</td><td></td></tr>
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Figure 2.0-1 Time Phasing of Data Management Data Bus Technology Goals

Other NASA activities in the area of high bandwidth/data rate transmitter and receivers which may be pertinent are:

a. NASA Goddard - Fiber Optics Bus System
Contact: T. Miller 301/344-6531

- Development contract with Sperry for hybrid receiver,

- 100 Megabit Manchester optical input, NRZ data and clock out intended for 100 MB packet switched passive star coupled network, 32 terminal systems.

b. Langley Monolithic Integrated Laser Transmitter - Photodetector Receiver
Contact: C. J. Magee 804/865-3418

Contract with RCA - work in preliminary stages.

c. MSFC 100 Megabit/Sec F/0 Bus.
Contact: D. Thomas 205/453-5728

Contract with OAO with ITT Roanoke as subcontractor for F/O portion. Transmitter and receiver are being developed by ITT. They have been delivered to OAO for integration into a distributed processing test bed. That optical system is capable of 16 terminal operation using a passive transmissive star configuration. The transmitter and receiver were implemented in discrete component form. The feasibility of implementation in hybrid form is uncertain.

Additionally, a number of companies are known to be active in the area of pigtailed optical device hermeticity either on internal or contract with funding. Full qualification to specific advanced platform requirements is expected to require NASA funding. The following are companies that are active in this area:

1. M/A COM/Laser Diode Labs
Contact: Jim McNeeley 201/249-7000

2. RCA
Contact: Jim O'Brien 717/397-7661

3. Optical Information Systems
   Contact: Rob Lucal 914/345-5850

It is recognized that these developments are at the component level and it is likely to be necessary to verify data management system performance at the systems level. This will require a system breadboard for which these developments could be an integral part. The plan for each technology has the following elements:

- Descriptions/Benefits
- Technical Approach
- Facility Requirements/Candidate Facilities
- Scheduling
- Resource Requirements

2.2 PIGTAILED OPTICAL SOURCE AND DETECTOR HERMETICITY

2.2.1 Description/Benefits

The interface between the optical transmission fiber and the optical sources and detectors is of major importance in design of optical data links. Use of lensed hermetic optical sources and detectors can produce a 15 to 25 dB coupling loss in the optical power margin at the source-to-fiber interface. This loss has a major impact on system capability. To reduce this problem, "pigtailed" devices have been utilized. These devices remove the lensed can from the sources and detectors and couple the fiber directly to the active region of the device. This results in lower coupling losses which could be in the 3-10 dB range, depending on fiber and device types used. Pigtailing currently uses non-hermetic devices which have a negative impact on reliability of the interface.

The development of hermetic pigtailed devices will improve data network reliability and performance since higher operating signal margins result in lower system error rates and reduced system sensitivity to fiber radiation damage. A more detailed description of applicable technology and benefits is provided in Volume II of this report.

2.2.2 Technical Approach

The following discussions relate to the numbered blocks in the flow diagram, figure 2.0-2. The steps in this preliminary implementation plan to provide qualified pigtailed hermetic devices (applicable to both sources and detectors) are described below.

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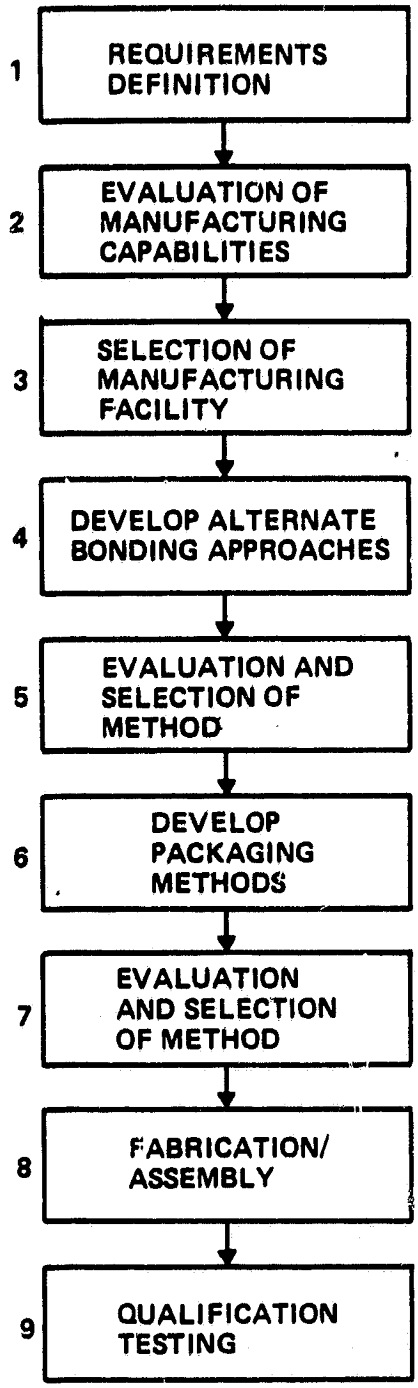

Figure 2.0-2 Flow Diagram for Task 1: Pigtailed Optical Source and Detector Hermeticity Technology Development

Step 1: Requirements Definition - The purpose of the initial task is to establish definitive development requirements. More definitive scheduling, task assignments, and end product specifications including identification of specific performance and environmental requirements for devices would be developed and documented in a requirements review package. In this task, and continuously through other development phases, this effort would be coordinated with space station data system network developers.

Step 2: Evaluation of Manufacturing Capability - A detailed evaluation of the status of producing devices capable of meeting the requirements would be performed in this step.

Step 3: Selection of Manufacturing Facility - Subsequent to Step 2, selection of one or more device manufacturing facilities would be made to complete development and qualification of the required pigtailed hermetic electro-optic sources and detectors.

Step 4: Develop Alternate Bonding Approaches - This involves elimination of epoxies currently used for internal bonding of device subassemblies. A group of solders with successively decreasing melting points could be selected to allow assembly of source and detector devices. A high melting point solder would be used at the first device assembly step proceeding to the lowest melting point solder for the last step. Using this hierarchy of solders is expected to allow development of hermetic fiber pigtailed optical sources and detectors. Other methods could be identified and developed also.

Step 5: Evaluation and Selection of Method - The advantages and disadvantages of each methodology would be assessed and the most promising method chosen. Selection criteria would include signal loss, reliability, maintainability, and suitability of materials for meeting hermeticity, temperature, and off-gassing requirements.

Step 6: Develop Packaging Methods - The incorporation of the fiber pigtail as an integral part of an electro-optic source or detector requires development of packaging techniques to provide strain relief for the fiber at its junction with the device enclosure. Where it exits the sealed volume, the fiber must be stripped of its normal buffer and protective jacketing in order to make a hermetic seal. The fiber buffer is of major importance in long term fiber strength since it provides a seal against moisture in addition to the strength contribution of the buffer itself. The moisture seal is extremely important in preventing formation and growth of micro-cracks in the fibers. These micro-cracks can ultimately cause fiber failure at stress levels far less than a buffered fiber can successfully withstand. Fiber strain relief to insure proper retention of the buffered and

jacketed fiber must be developed. Strain relief must prevent stress application to the unbuffered region of the fiber immediately adjacent to the heremetic fiber-to-enclosure seal.

Step 7: Evaluation and Selection of Method - The advantages and disadvantages of each methodology would be assessed and the most promising method chosen. Selection criteria would include hermetic performance, strength, reliabilty, size, and interface commonality.

Step 8: Fabrication/Assembly - Prototype devices designed to incorporate the methods selected above would be fabricated and assembled for test and evaluation.

Step 9: Qualification Testing - This is testing to verify that performance and environmental requirements are met and will result in space qualified hermetic pigtailed sources and detectors for use in advanced platform system design.

2.2.3 Facility Requirements/Candidate Facilities

The facilities necessary to support the recommended developments are listed below.

(A) The development of bonding technology will require fiber optic cabling and a test interface that measures source and detector couplings in order to establish optimum positioning. This fixture would be instrumented to determine the loss of signal across the interface. Seal strength and heremetic integrity against the expected ambient environments of the space station would be tested.

(B) Performance testing on the completed device can be accommodated in almost any electronics development laboratory with the capacity to build breadboard electronics packages for space applications.

(C) (Optional) New bonding approaches may require new materials. If so, the material will have to undergo space qualification testing to meet off-gassing, electrical conductivity, and other compatibility analyses.

(D) (Optional) The simulation facility discussed in the Data Management Architecture Plan could serve as a good facility for the test requirements presented here (see section 3.0).

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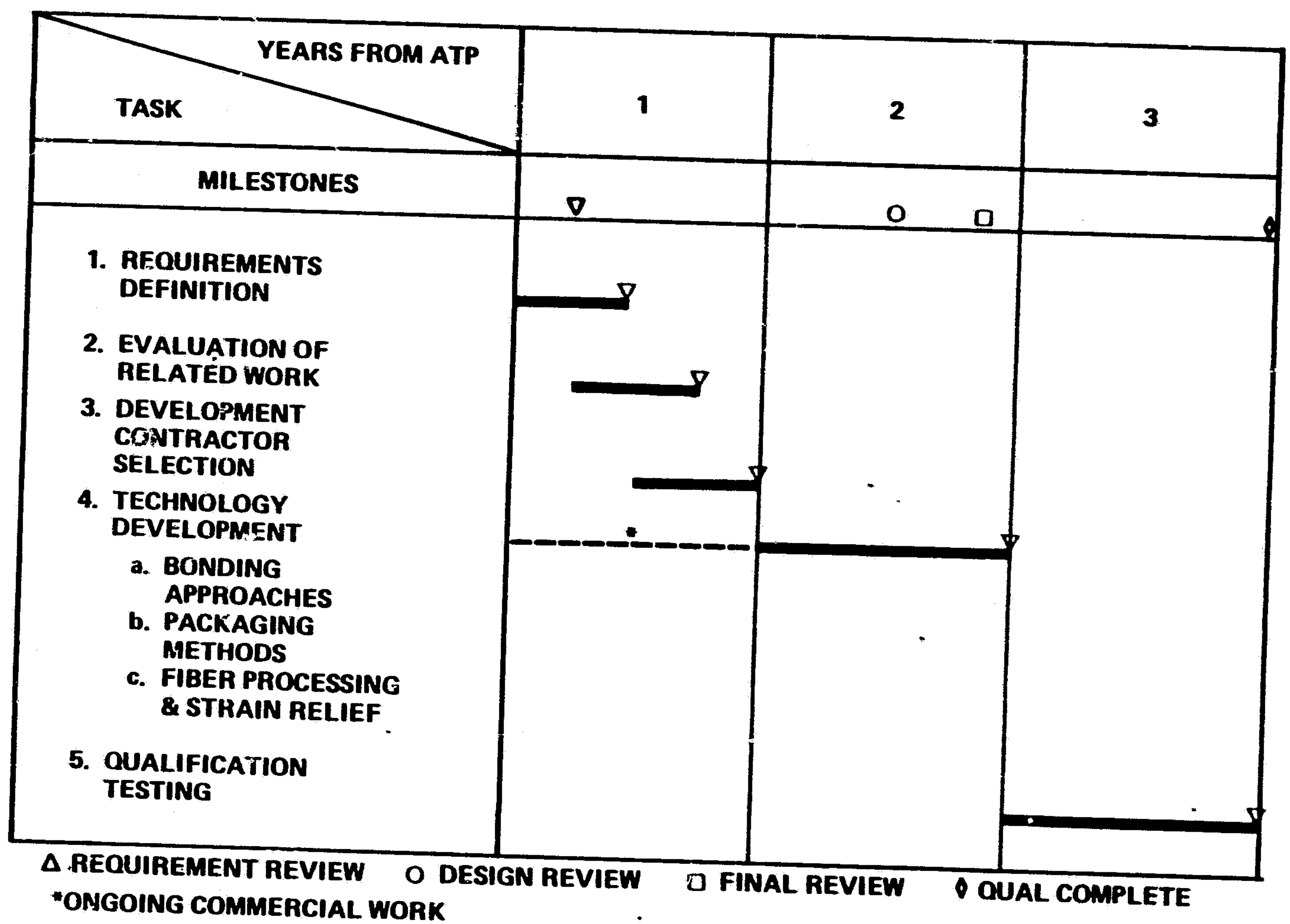

Figure 2.0-3 Pigtailed Optical Source and Detector Hermeticity Technology Development Schedule

A number of companies are known to be engaged in developing technology closely related to that required for the space station. For that reason, candidate facilities will probably include some contractor installations such as those presented in the introduction. A tabulation of NASA facilities related to the data management technology area are provided in table 2.0-2. MSFC facilities specifically intended for development of data system components are identified with an asterisk (*). Based on this facility review, no requirements for new facilities have been identified to support the development of pigtailed hermetic source and detector devices.

2.2.4 Schedules

The major milestone schedules for the development of pigtailed, hermetic source and detector technology is shown in figure 2.0-3. Estimated time frames for each major development phase and their relationship to programatic milestones are indicated. This schedule could support a new start in FY86 and also provide evaluation models for Data Management System breadboard testing.

2.2.5 Resources

Estimated time-phased resource requirements for the fiber optic coupler development efforts are shown in table 2.0-3.

2.3 HIGH BANDWIDTH/DATA RATE INTEGRATED CIRCUIT TRANSMITTERS AND RECEIVERS

2.3.1 Descriptions/Benefits

The benefits of fiber optics in increased bandwidth/distance capability, low weight, and other factors described in Volume II has driven the choice of developing integrated circuit optical transmitters and receivers to replace current discrete/hybrid approaches. High data rate and bandwidth requirements for handling the volumes of scientific data, telemetry, communications and video signals required for a long life space station could be satisfied with a fiber optics network. Use of integrated circuit fiber optic transmitters and receivers offers significant cost and weight reductions and improved reliability compared to a discrete/hybrid approach.

TABLE 2.0-2
FACILITY CANDIDATES FOR DATA MANAGEMENT DATA BUS TECHNOLOGY DEVELOPMENT

ID CODE	NASA CENTER AND FACILITY NAME
	Marshall Space Flight Center
4487-EC-11	Electronics Lab
4487-EC-12	Control and Display Lab
4708-EF-8	*Digital Techniques Development Laboratory
4708-EF-11	Electronc Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
	Johnson Space Center
440	*Communications Component Development Laboratory
440	Command and Modulation Laboratory
16	*Instrumentation Systems Laboratory
16, GE V	Checkout Systems Development Laboratory
15	Laboratory, Spacecraft Data Systems
440	Electro-Optical Television Systems

PT-0441

Table 2.0-3 *Resource Requirements for Pigtailed Optical Source and Detector Hermeticity Technology Development Program*

TASK \ YEARS FROM ATP	1	2	3	4	TOTAL	REMARKS
TASK 1: PIGTAILED OPTICAL SOURCE AND DETECTOR HERMETICITY						• PRESENT YEAR DOLLARS • FIGURES IN $1000
(1) REQUIREMENTS DEFINITION	25	–	–	–	25	
(2) EVALUATION OF DEVICE MANUFACTURING CAPABILITIES	15	–	–	–	15	
(3) SELECTION OF MANUFACTURING FACILITY	10	–	–	–	10	
(4) DEVELOP ALTERNATE BONDING APPROACHES	25	100	–	–	125	
(5) EVALUATION AND SELECTION OF BONDING APPROACH	–	20	–	–	20	
(6) DEVELOP PACKAGING METHODS	–	65	–	–	65	
(7) EVALUATE AND SELECT PACKAGING METHOD	–	20	–	–	20	• ESTIMATES ASSUME APPLICABILITY OF ONGOING INDUSTRY WORK
(8) FABRICATION/ASSEMBLY	–	–	110	–	110	• QUALIFICATION OF EXISTING TECHNOLOGY FOR SPACE APPLICATION
(9) QUALIFICATION TESTS	–	–	110	–	110	
TOTAL	75	205	220	–	500	

2.3.2 Technical Approach

Parallel and synergistic development of transmitters and receivers is proposed and depicted in the flow diagram of figure 2.0-4. After an initial requirements definition, transmitters and receivers go through similar schedules involving specifications, breadboard, evaluation, prototype component design and fabrication and qualification testing. Close coordination of the tasks that follow is indicated to insure the compatibility of the end products.

Step 1: Requirements Definition and Evaluation of Related Work - The purpose of this task is to identify specific performance and environmental requirements to be met for the advanced space platform application. A review and evaluation would be conducted of on-going NASA and industry activities in the area to determine similarities which may exist and determine the most promising approaches to satisfy the specific advanced platform requirements.

Step 2: Develop Specifications - Detailed specifications (transmitter and receiver) would be established based on the requirements defined above. If it is decided to have this work performed by one of the several qualified contractors who have in-place the facilities and talent for this development, the selection process could be performed in this step.

Step 3a: Breadboard Circuit Design, Test, and Evaluation - Conceptual development and design of transmitter and receiver units could now be accomplished. This may be an iterative process to converge on a single design that can be verified by breadboard evaluation. The design must be compatible with other components in the space station data network. Next, manufacturing and assembly of breadboard models of the transmitter and receiver designs with fiber optic sources and detectors would be accomplished. Installation of check-out instrumentation would be included. The breadboard could be operated at performance levels and in environments according to the specifications. Performance would be evaluated to determine any weaknesses of the design. These weaknesses could then be resolved.

Step 3b: Integrated Circuit Design - Based on the breadboard design developed in the previous steps, the design of an integratnd circuit version of the breadboard is next.

Step 3c: Prototype Fabrication and Test - The integrated circuit will be fabricated and performance tested individually (i.e., before being incorporated in transmitter or receiver units). Upon successful completion of the IC, a development process for packaging them

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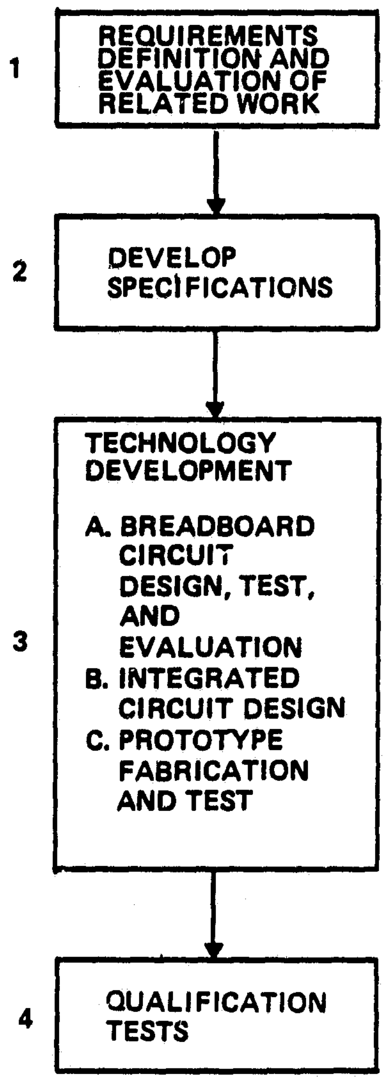

Figure 2.0-4 Flow Diagram for High Bandwidth/High Data Rate Integrated Circuit Transmitter and Receiver Component Technology Development

into transmitter and receiver units will proceed. Refinement of the units will continue through a set of prototypes until manufacturing and packaging irregularities are resolved in production and performance tests.

Step 4: Qualification Testing - Operation of the final prototype in simulated environments of the space station will follow to verify the capability of the units. Actual testing of hardware for qualification as a flight article is part of the space station design task and is not the intent of this step.

2.3.3 Facility Requirements/Candidate Facilities

Because of the similarities between components involved in receivers and transmitters, the same facilities could be used for tests associated with both. The electronics component development laboratory identified in section 2.2.3 for the optical coupler is the same type facility required for breadboard design, fabrication, and evaluation of transmitters and receivers. Based on This facility review, no new facilities should be necessary to support this development.

2.3.4 Schedules

The schedule and major milestones for the development of high bandwidth/data rate integrated circuit transmitters and receivers is shown in figure 2.0-5. Estimated time frames for each major development phase are indicated. As defined by the RCA Model, this schedule will not provide the technology by FY86 since qualification cannot be completed before mid-1988. However, with rapid initiation of the advancement program and increased prioritization, the schedule could be compressed to 4-5 years.

2.3.5 Resources

The time phased resource requirement estimates for the transmitter and receiver development efforts described are shown in table 2.0-4.

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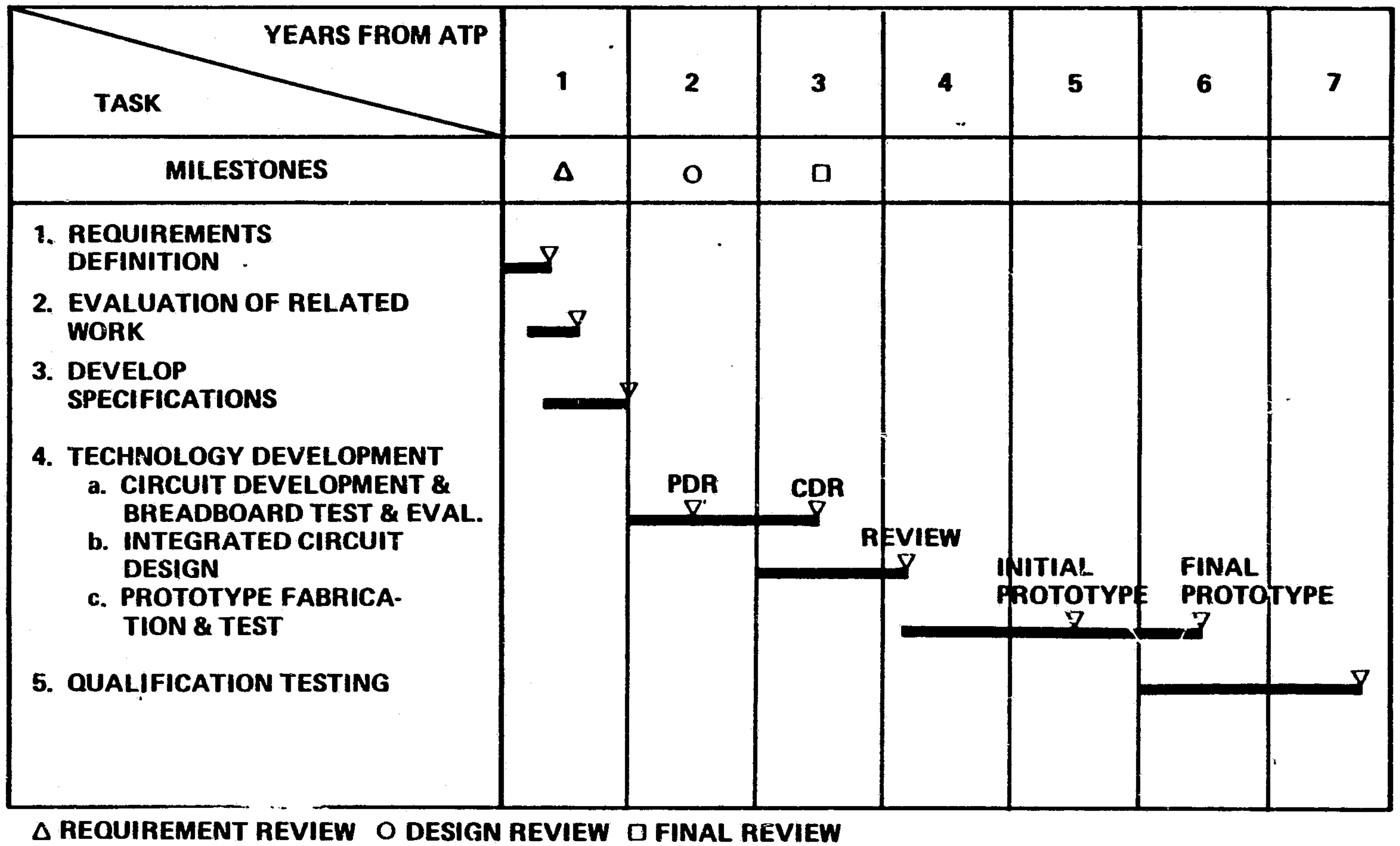

Figure 2.0-5 High Bandwidth/High Data Rate Transmitter and Receiver Technology Development Schedule

Table 2.0-4 Resource Requirements for High Bandwidth/High Data Rate Integrated Circuit Transmitter and Receiver Technology Development Program

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TASK \ YEARS FROM ATP	1	2	3	4	5	6	7	TOTAL	REMARKS
TASK 2: HIGH BANDWIDTH/DATA RATE TRANSMITTERS & RECEIVERS									• 1984 DOLLARS • FIGURES IN $1000
REQUIREMENTS DEFINITION	40							40	
RELATED WORK EVALUATION	20							20	
DEVELOP SPECIFICATIONS	35							35	
TECHNOLOGY DEVELOPMENT		1500	1200	1200	1300	600		5800	
QUALIFICATION						700	675	1375	
TOTAL	95	1500	1200	1200	1300	1300	675	7270	

3.0 DATA MANAGEMENT ARCHITECTURE TECHNOLOGY ADVANCEMENT PLAN

3.1 INTRODUCTION

The purpose of this plan is to define a program that will achieve the goal of providing local area network data management technology specifically tailored to the needs of an early space station. In addition to identifying the tasks and issues to be resolved at the data management system level, the development of components of the network architecture is also considered. The development of a space station local area network must consider a standard approach to component development and their interrelationships. Consequently, this section is comprised of a single plan with interdependent tasks which meet the near-term requirements and support evolutionary space station goals. Section 3.2.2 of Volume II describes the space station requirements in detail. Required capabilities as determined by the study are as follows:

1) realtime control functions (i.e., attitude, power, thermal)
2) instrumentation data collection (digital)
3) digital voice communication
4) high bandwidth video distribution
5) high speed bulk data communications
6) interprocessor communications
7) online and archival mass storage
8) scientific computation
9) signal/image processing

The tech, logy advancement steps that are described focus on satisfying the early data management and communications requirements of the space station and, over time, evolving needs. The capability of hardware and software currently available, or under development which can satisfy some of these requirements, has been assessed. The advancement steps emphasize the development of simulators for early verification of architecture options. These simulators can support the definition of a data management breadboard which incorporates advanced components and allows direct interfaces with functions such as on-board displays of information.

Since the overall system design is not defined to the level to support development of all subsystems, a requirements definition task is needed in some areas. Even then, the development of a local area network breadboard would be necessary to provide proof of

concept. This will allow the development of applicable technology to proceed while the space station design is in the initial phase, allowing local area network technology to be ready to support a FY86 new start. The system level trades conducted in this study have identified the following components as significant elements of the data management system necessary to support the development and integration of space station subsystems and applications:

(1) Network Interface Modules (for subsystem interconnections)
(2) Network Operating System (for communications and control), and
(3) Gateway Interfaces into existing and future systems (e.g., STS).

While the list above does not include all elements of the data network requiring technology advancement, it does represent the major contributors and is sufficient to allow development of a viable data management system. It is recognized that two types of approaches are required for component and system level developments. Both are integrated in the following development step descriptions.

3.2 LOCAL AREA NETWORK

3.2.1 Description/Benefits

The distributed architecture of the space station dictates a communications network. Based on the trade study results presented in the other volumes of this report, significant benefits can be derived from a data management architecture which provides fault tolerant control systems, distributed and embedded microcomputers, video distribution capability, and a gateway configuration which has upward compatibility.

A fault tolerant control system appears mandatory for both manned and unmanned space stations. Distributed systems are expected to be cheapter and more reliable than closely coupled or centralized computers, especially if the system is partitioned into critical and non-critical segments. Video distribution is necessary for docking, manipulator, tele-operator EVA and imaging sensor activities and advanced displays are required to be in several locations. A gateway architecture allows modification over its lifetime to take advantage of improvements in technology in these areas.

Additionally, fiber optic local area networks appear to be derivable from existing technology. Microelectronic components are now becoming available that will permit the

development of radiation tolerant, low power, lightweight computer systems that will quickly drive existing spacecraft computers into obsolescence. The accomplishment of the steps in this plan for standardizing this equipment for space station applications could potentially lower integration costs at phase C/D of the space station data management system by as much as 75% (see Volume II, Section 3.3.4).

3.2.2 Technical Approach

An overall logic flow for this plan is presented in figure 3.0-1. The numbered blocks of the diagram relate directly to the steps outlined below which describe the tasks associated with this technology development from initial requirements definition to ground-based verification testing of hardware and software at the system level.

Step 1: Requirements Definition - This task involves the synthesis of space station design and operational requirements to provide a sound basis for simulator development. Design guidelines could be derived in detail, yet remain general in areas where new technology may overtake the design process. All inputs to the data management system would need to be identified along with the functional specifications.

Step 2: Conceptual Design of System - The wide range of interfaces to the data management system dictate design requirements that overlap electrical power, thermal, EC/LSS, and other subsystem requirements. The architecture of the space station network must be designed to meet these requirements. The scope of design definition would be limited to the data rates, formats, and protocols needed for channeling commands, instrument data, and communications. It would not define the control laws for those systems whose information it handles, but provide a fault tolerant and reliable network for data transmission and storage associated with the variety of subsystem/components.

As indicated, the data management system definition would include berthing port and subsystem interfaces and gateways to other systems (i.e., Space Shuttle). This facilitates space station evolution by standardizing and modularizing the network and permitting growth to be accommodated at the berthing ports. An approach for providing design guidelines on the make-up of these interfaces and gateways is shown in figure 3.0-2.

Step 2(a): Definition of Individual Module Requirements - The process begins with a characterization of each individual module or element of the data management network and the required interfaces.

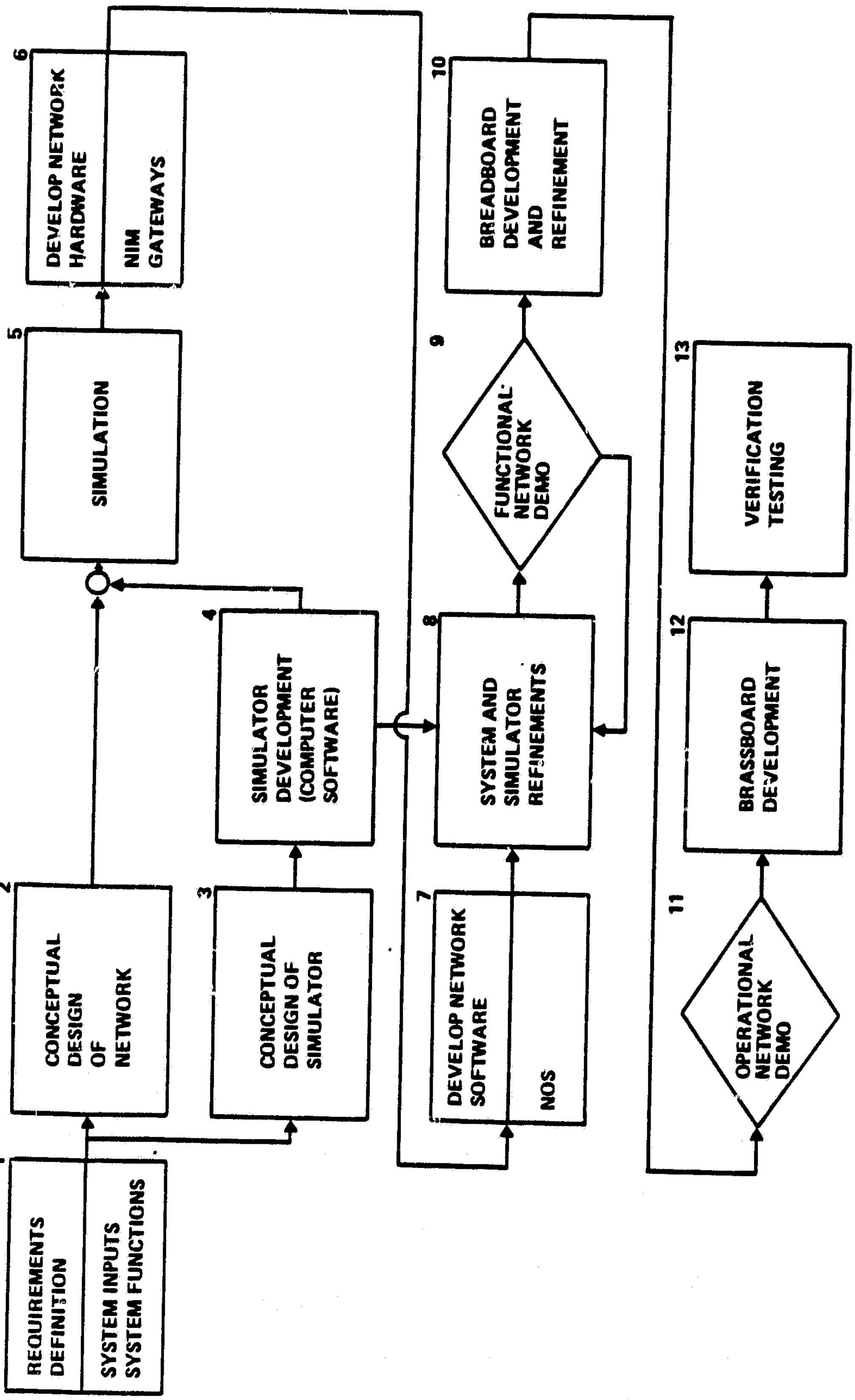

Figure 3.0-1 Data Management Architecture Technology Development Flow

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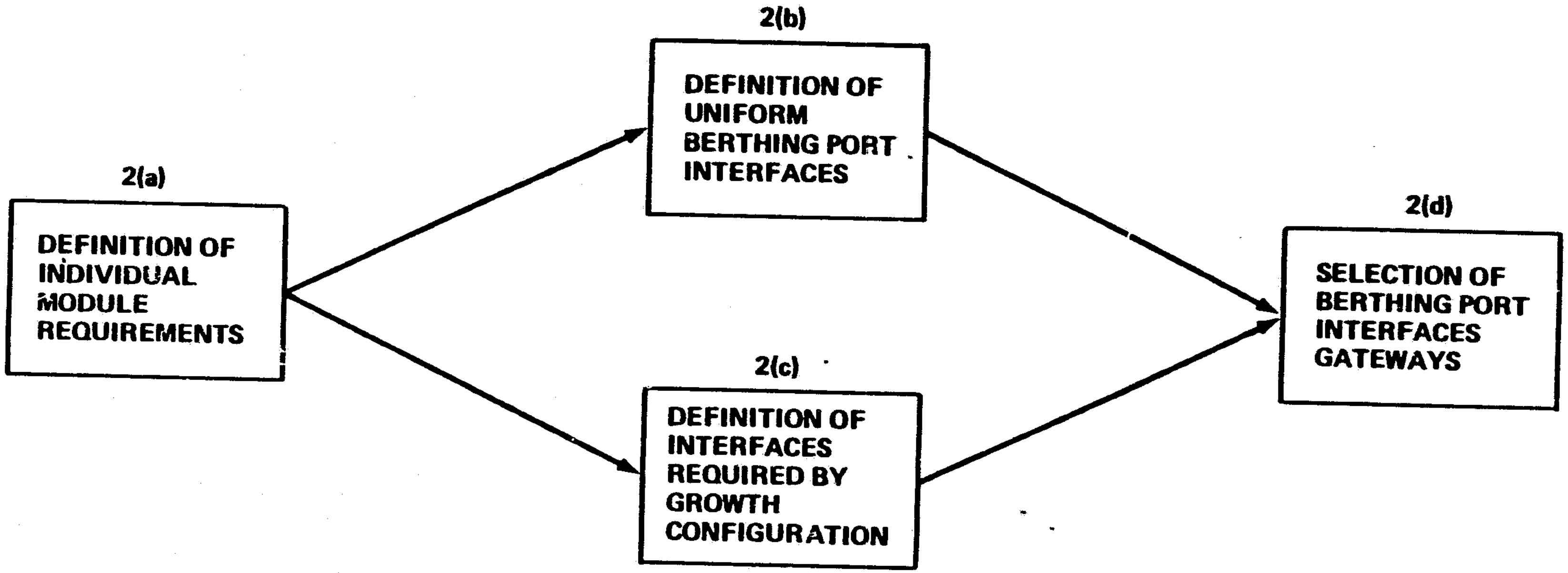

Figure 3.0-2 Identification of Data Management Interfaces and Network Gateways

Step 2(b): Definition of Uniform Berthing Port Interfaces - A uniform berthing interface will be defined so that all basic configurations can be accommodated without change.

Step 2(c): Definition of Interfaces Required by Growth Configuration - The growth options for each candidate confiuration must be assessed and additional interface requirements identified.

Step 2(d): Selection of Interfaces and Gateways - The purpose of the previous subtasks was to establish the interface requirements based on configuration, module element characteristics, and evolutionary philosophy. These requirements provide background for the placement and definition of berthing port interfaces and gaetways.

Step 3: Conceptual Design of Simulator - In parallel with the conceptual design of the system, simulation models of components can be developed for requirements analysis. Initially, the simulator will consist entirely of non-realtime computer simulator software. Component characteristics identified in the requirements definition (Step 1) can be accommodated in the conceptual desing (Step 2).

Step 4: Simulator Development (Computer Software) - Actual coding and debugging of the software is performed in this step.

Step 5: Simulation - The models will be exercised to analyze the conceptual design. Studies will be performed to discover any design defects and detect bottlenecks and critical failure modes.

Step 6: Development of Network Hardware - Next, laboratory models of network hardware will be fabricated and tested. In this step and the next, actual hardware and software components of the breadboard are developed and integrated. Particular tasks associated with the development of network components should include:

Network Interface Module (NIM): The Network Interface Module is an electronic switching unit that provides access to the data management network for processors, instruments and other equipment requiring data communications, storage or processing support. It will include interfaces for serial data buses, video cameras and displays and the various subsystems, connecting these devices to equipment in other modules, by means of similar interfaces at the remote locations. Fiber optics would be used to interconnect the NIMs, providing high speed multiplexed data paths

between the modules. It will be necessary to simulate the function of the NIMs, and the interactions of the subsystems before the NIM hardware and control software can be fully characterized. The development of prototypes and flight hardware can then proceed, as described in the following pages.

Gateways (Into Other Systems): Gateways are the generally accepted approach for interfacing incompatible networks or complete systems with one another. Gateways consist of electronic circuitry to provide a physical interface, plus associated control and communications software to provide logical interoperability. Gateway development will be particularly valuable if shuttle - compatible equipment is used early in the program. A shuttle gateway will also have to be developed for space testing subsystems, and for later use, when the shuttle docks at the berthing ports of the operational system. The issue of interoperability is a serious one and must be addressed early in the development program. The following pages describe the schedule and costs in greater detail.

Step 7: Development of Network Software - The software associated with operation of the hardware will be developed and verified. Additionally, development of the network operating system described below will proceed.

Network Operating System (NOS): The Network Operating System includes all software used to provide control, communications and data storage within the network. It does not include applications software that is specific to particular equipment or subsystems. The performance of this software must be simulated so that design errors, critical failure modes, or bottlenecks do not occur. Many such problems are configuration dependent and would not be discovered without simulation and testing under realistic conditions. Therefore, simulation capabilities will be needed early in the development program and simulation will continue well into the operational phases. The NOS software will require extensive testing and verification. This testing will be carried out on the ground and the NOS will be used to support breadboard development. Early use of this software will provide valuable experience for later developments.

Step 8: System and Simulator Refinement - At this point, simulation activities can move to a laboratory facility. The configuration of laboratory equipment would reflect the functional elements fo the data management system and the subsystems it serves. Crew stations and network interfaces can be arranged to allow growth to support the

development of breadboards and flight hardware. The development of network topology can then proceed using selected concepts (e.g., graph, chordal ring). The topology can be validated and varied if necessary to achieve higher system efficiency or fault tolerance.

Step 9: Functional Demonstration of Network Interfaces - The approach described in previous steps involves analysis of different configurations and methodologies. This step represents the evaluation of completed options. Laboratory configurations can be modified until performance meets necessary standards and all concepts selected have been sufficiently evaluated.

Step 10: Breadboard Development and Refinement - This task can be initiated with a survey of recent technology developments in data management, particularly in microprocessor technology. Selection of equipment for a flight prototype can follow. Existing flight-rated equipment can be selected where possible but design and fabrication of new equipment will be necessary in the replacement of simulating devices with flight-rated hardware. At this point, the verification and integration of system control functions, communications protocols, and the network operation system can be started.

Step 11: Operational Demonstration with Control Functions - Since the development of the breadboard data management system described involves analysis of a variety of concepts in control hierarchy and operating methodologies, this step represents the evaluation of several options. Iterations back to further breadboard development (Step 10) may be required. These iterations can continue until performance meets necessary standards and all concepts selected have been sufficiently evaluated at this point.

Step 12: Brassboard Development - This step involves the development of integrated circuit components from the breadboard hardware components.

Step 13: Verification Testing - The completed brassboard can become the model for development of the flight hardware to be used on the space station. Testing will include operation of the brassboard network in space environments. Flight hardware fabrication and qualification testing of the data management system for the early space station is considered part of the vehicle design process rather than technology development and is not included as part of this plan.

3.2.3 Facility Requirements/Candidate Facilities

The facilities required to produce the architecture simulator could have basically three configurations/generations and can be developed in an evolutionary fashion with the simulator. Therefore, it is important to choose initial facilities and equipment with the capability to growth to satisfy all developmental requirements. This test/facility description includes only the basic command, control, and communications functions. It is noted, however, that it may be desirable to accommodate the mid-term and far-term developments shown in table 3.0-1 in this facility. Facility requirements necessary to support the recommended development include the following.

(A) Because the first generation simulator will be primarily software, it does not specifically require development in the same facility in which later generations will be developed. Portions of the software will be applicable to later generations of the simulator, therefore it is desirable that the computer on which the initial software is developed be as compatible as possible with the laboratory equipment to be used later. This will facilitate transfer of software.

(B) The second and third generation systems will require a dedicated facility where actual hardware and subsystem simulators can be incorporated into the network. Components will ultimately be flight-rated where possible. The facility could require thousands of square feet floor space that can be divided into bays or laboratories areas supporting the space station modules and subsystems. A partial list of necessary equipment is given in Table 3-1 under the headings of second and third generation network.

An illustrative tabulation of NASA faciliites applicable to data management system development work is provided in table 3.0-2. MSFC has facilities directly applicable to the development of the data management network breadboard. Additionally, breadboard developments in thermal and power systems at MSFC could be supported by the network. JSC also has facilities that will handle breadboard development and on-going work in the EC/LSS and could similarly benefit from the installation of a data management network. Areas identified for the first generation simulator are denoted by an asterisk (*). Others are potentially applicable to part to all of the second and third generation network systems. Based on this facility review, no new facilities should be necessary to support the data management architecture technology program.

Table 3.0-1. Data Management Architecture Components for First Three Network Generations

1ST GENERATION	2ND GENERATION	3RD GENERATION
• MAIN FRAME SCIENTIFIC COMPUTER • SIMULATION LANGUAGE AND COMPATIBLE COMPILER(S) • PERIPHERALS: • DISCS • LINE PRINTER • CRT TERMINALS WITH GRAPHIC CAPABILITY • HARDCOPY UNIT • PRINTER • MODEM (POSSIBLY) • UTILITIES	• NETWORK INTERFACE MODULE • NETWORK OPERATING SYSTEM • GATEWAYS • MICROCOMPUTERS • BREADBOARDS • CREW STATIONS • CABLES • CONNECTORS • CABLE TRAYS • EC LAB TOOLS (OSCILLOSCOPES, METERS, HAND TOOLS, BRACKETS, ETC.)	• 1986 BASELINE TECHNOLOGY COMPONENTS • BRASSBOARDS • DEVELOPMENT OF FLIGHT HARDWARE

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TABLE 3.0-2
FACILITY CANDIDATES FOR DATA MANAGEMENT ARCHITECTURE DEVELOPMENT LABORATORY

ID CODE	NASA CENTER AND FACILITY NAME
	Marshall Space Flight Center
4487-EC-11	Electronics Lab
4487-EC-12	*Control and Display Lab
4487-EC-14	Electronics Circuit Development Lab
4487-EC-16	*Microprocessor Applications Laboratory
4487-EC-20	Optical Test Lab
4487-EC-24	Optical Test and Fabrication Facility
4487-EC-35	Electrical Component Development Lab
4487-EC-45	Optical Shop for Fabrication of Optical Elements
4487-EC-48	*Microprocessor Laboratory
4659-AC-1	*Univac 1100/82
4659-AC-2	*Univac 1108
4708-AC-1	*IBM 360/75 General Purpose Computer System
4708-EF-8	*Digital Techniques Development Laboratory
4708-EF-11	*Electronc Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
4708-EF-14	*Integrated Software Development Facility
4708-EF-20	*Experiment Data Systems Integration Lab
4708-ET-10	Payloads and Systems Test Laboratory
	AMES Research Center
N-233	Central Computer Facility
	Johnson Space Center
440	*Communications Component Development Laboratory
440	*Command and Modulation Laboratory
15	*Laboratory, Spacecraft Data Systems
440	Electro-Optical Television Systems
	Langley Research Center
1268	*Data Reduction Center

3.2.4 Schedules

The major milestone schedule for the development of the space station local area network is shown in figure 3.0-3. The estimated time frames for each major development phase are indicated. This schedule identifies the near term developments and should not be intepreted as the basis for development of a complete space station data management system. The advanced station technology will grow from these early developments which are necessary for requirements definitions and program start-up. This schedule could support a space station start in FY86 and can also provide a local area network and data management system for testing far term developments as well as power, thermal, and EC/LSS near term breadboards.

3.2.5 Resources

The time phased resource requirements estimates for the local area network technology development program are shown in table 3.0-3.

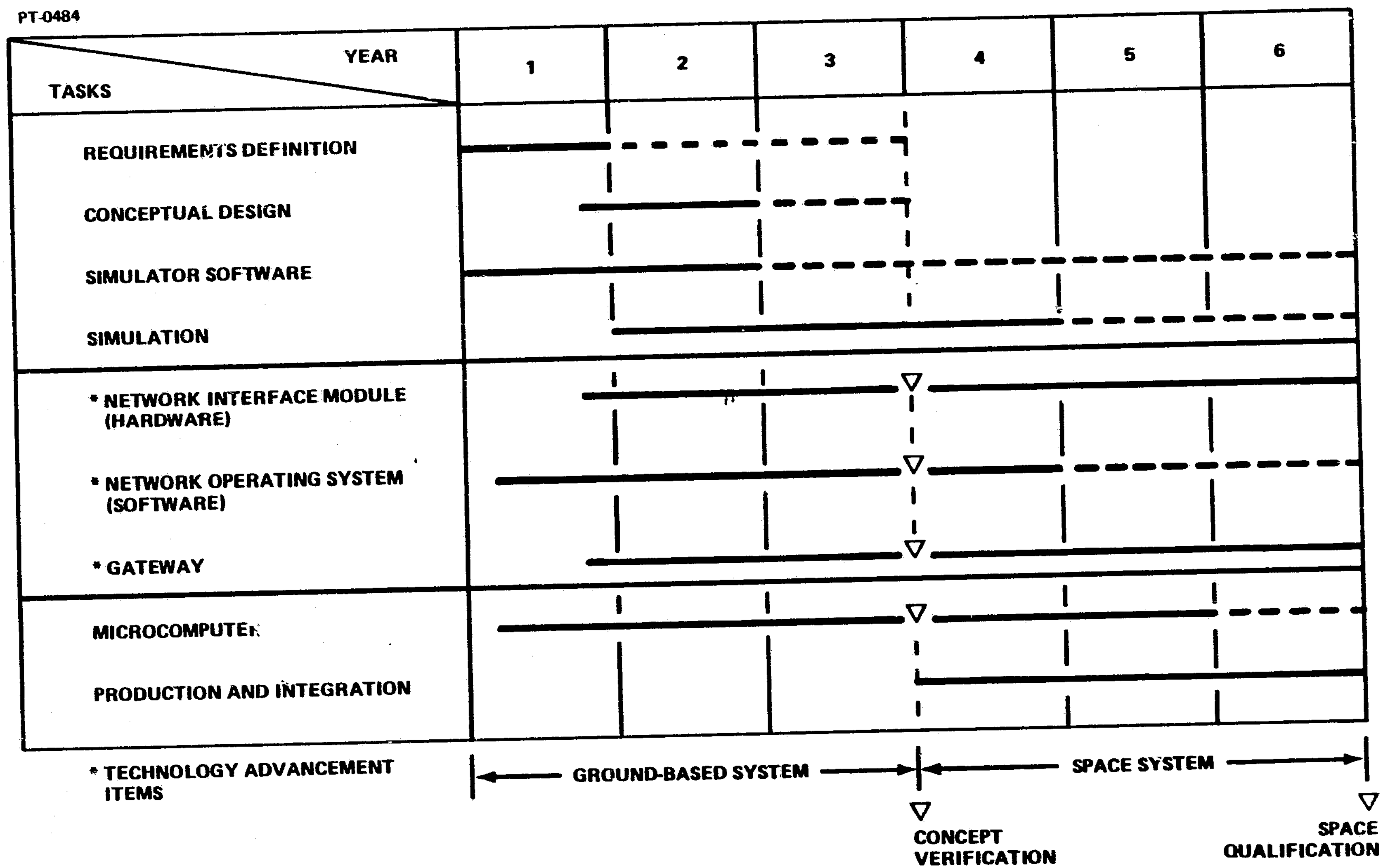

Figure 3.0-3 Data Management Network Development Schedule

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Table 3.0-3 Data Management Network Development Resources

TASK YEAR	1	2	3	4	5	6	TOTALS
REQUIREMENTS DEFINITION	700	350	300	–	–	–	1350
CONCEPTUAL DESIGN	200	800	350	–	–	–	1350
SIMULATOR SOFTWARE	650	750	200	100	100	100	1900
SIMULATION		500	750	650	200	150	2250
* NETWORK INTERFACE MODULE	250	650	900	2700	2700	2400	9600
* NETWORK OPERATING SYSTEM	500	700	1700	1700	800	600	6000
* GATEWAY	300	900	1250	6000	6500	5250	20200
MICROCOMPUTER	400	650	1250	1500	1500	900	6200
PRODUCTION & INTEGRATION	–	–	–	1650	4000	9500	15150
TOTALS	3000	5300	6700	14300	15800	18900	64000

*TECHNOLOGY ADVANCEMENT ITEMS

GROUND-BASED SYSTEM $15M | SPACE-QUALIFIED SYSTEM $49M

4.0 INTEGRATION OF AUTOMATED HOUSEKEEPING TECHNOLOGY ADVANCEMENT PLAN

4.1 INTRODUCTION

The integration of automated control systems for space station housekeeping subsystems such as the environmental control and life support subsystem (EC/LSS), electrical power subsystem, and thermal control subsystem would significantly benefit space station design and operation. As indicated by the results of the trade studies reported in Volume II of this report, benefits could be obtained through reduction of resupply costs, monitoring costs, and maintenance cost. The following discussion describes a technology development plan which could provide benefits in efficiency, safety, and maintainability and accommodate space station evolution. Near-term and evolutionary automation goals are summarized in table 4.0-1.

The critical areas identified by the system level trades are:

- o Sensor Technology Development for EC/LSS
  - Total Organic Carbon (TOC) Sensor
  - Ammonia (NH_3) Sensor
- o Overall Expert Systems Development
  - Control Hierarchy Concepts
  - Control Rules and Data Development
  - Control Interfaces with Crew.

These areas do not represent a total delineation of technology items requiring development to support space station housekeeping designs but do represent high leverage technologies, which are needed for initial and early evolutions of the space station. A survey of related RTOP's for FY82 (illustrative activities are shown in table 4.0-2) indicates that the technology base is being developed in this area but could be expanded to meet additional needs.

While the specific goals of this plan are unique, the integration of automated housekeeping functions impacts not only the subsystems mentioned but the data management area as well. The architecture of space station data management must support the design requirements imposed by these developments. The plans for each technology advancement associated with integration of automated housekeeping need to be integrated with requirements determination for the space station data management system.

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Table 4.0-1 *Time Phasing of Integrated Automation of Housekeeping Technology Advancement Goals*

TIME PHASE	NEAR TERM	EVOLUTIONARY
EVOLUTION	BASIC MANNED SPACE STATION	SECOND ORDER MANNED SPACE STATION

CONTROLLER DEVELOPMENT	<u>BASELINE AUTOMATION</u>
	• FAULT ISOLATION
	• AUTOMATION OF REGENERATIVE EC/LSS
	• POWER SYSTEM ENERGY BALANCING
	• THERMAL MONITORING & CONTROL
	• ATMOSPHERIC MONITORING & CONTROL
		<u>OVERALL EXPERT SYSTEM</u>
		• INTEGRATED AUTOMATION OPTIMIZATION
		  • RULES ESTABLISHMENT
		  • IDENTIFICATION OF DATA ITEMS
		  • ALGORITHM DEVELOPMENT
		  • INTERACTION FACILITIES
		  • SUBSYSTEM MODELS
		• CONTROL OF EMERGENCY REPRESSURIZATION GASES

EC/LSS SENSOR TECHNOLOGY	• RELIABLE TOTAL ORGANIC CARBON (TOC) • AMMONIA (NH_3) • SELF CLEANING PH • LIQUID LEVEL • LIQUID FLOW RATE • IODINE DETECTOR • RELIABLE HUMIDITY • CONDUCTIVITY	• ZERO-G SENSOR DEVELOPMENT • DEBUG FIRST GENERATION SENSORS • DEVELOP NEWLY REQUIRED SENSORS IDENTIFIED AS A RESULT OF REGENERATIVE EC/LSS TEST BED FLIGHT VERIFICATION

TABLE 4.0-2. FY82 RTOP SUBMISSIONS RELATED TO INTEGRATION OF AUTOMATED HOUSEKEEPING TECHNOLOGY DEVELOPMENT

CENTER	TITLE	OBJECTIVES	BENEFITS
ARC	Advanced life support system	o Investigation of specific life support subsystem technology and generation of conceptual designs	o Low maintenance, high reliability, and long life regenerative life support systems
JSC	Advanced life support systems	o Identify requirements and develop technology required to provide metabolic support systems for the next generation, long duration, manned space missions	o Provide alternate concepts resulting decreased expendable requirements, increased reliability, and maintainability, and increased crew performance
LaRC	NASA end-to-end data system: information adaptive system and on-board data storage	o Develop and demonstrate an on-board spacecraft data system which adaptively controls and process high speed, multi-spectral sensor data	o Simplication of sensor data reduction resulting in greater utility of data. Reduction in requirement for ground processing should reduce the possible number of single point failures.
MSFC	Space applications of Automation, Robatics, and Machine Intelligence Systems (ARAMIS)	o Evaluate the value and benefits of ARAMIS to projected space and related ground activities	o Improved economy in performance, life cycle, and cost of erecting and operating a space platform

4.2 SENSOR TECHNOLOGY ADVANCEMENT FOR EC/LSS

Various sensors will be required to support electronic sensing functions of automated housekeeping controllers. Volume II of this final report provides a list of the major types of sensors that will be required. Of those listed, the total organic carbon (TOC) and ammonia (NH_3) sensors were chosen to be addressed here. Based on assessments by specialists working with partially regenerative EC/LSS's, these sensors represent the most critical Space Station sensor technology advancement needs and are not adequately covered in existing development planning.

4.2.1 Technical Approach

The steps in developing the TOC and NH_3 sensors are related due to similarities in the items themselves. For this reason, the following descriptions of the major elements are applicable to either sensor. A flow diagram for these elements is depicted in figure 4.0-1.

Step 1: Requirements Definition - An additional study phase could be performed to identify potential additional requirements, design guidelines, and other study outputs that may have been overlooked in earlier program definition. More definitive scheduling, task definitions, and end product specifications could be defined and documented in a requirements review package.

Step 2: Develop Sensor Concepts - The definition of sensor concepts could address several areas of interest including materials, electrodes, and processes. Automatic calibration concepts could be developed including investigations into the generation of calibration gas, solutions in conjunction with electrodes, and electrical calibration.

Step 3: Sensor Designs - In this step, a preliminary conceptual design can be derived from the concepts defined in Step 2. Design approaches could address membrane development, its durability, and compatibility with fluids.

Step 4: Evaluate Concepts and Designs - The purpose of this activity is to identify any weaknesses and then to develop solutions to eliminate problem areas. The majority of analyses in steps 2, 3, and 4 are intended to be based on theory, research, and possibly some computer-aided design techniques. However, it may be possible to pursue some basic developments in the laboratory such as membrane fabrication and testing. For those items, this step could involve immersion in solutions to test the viability of samples.

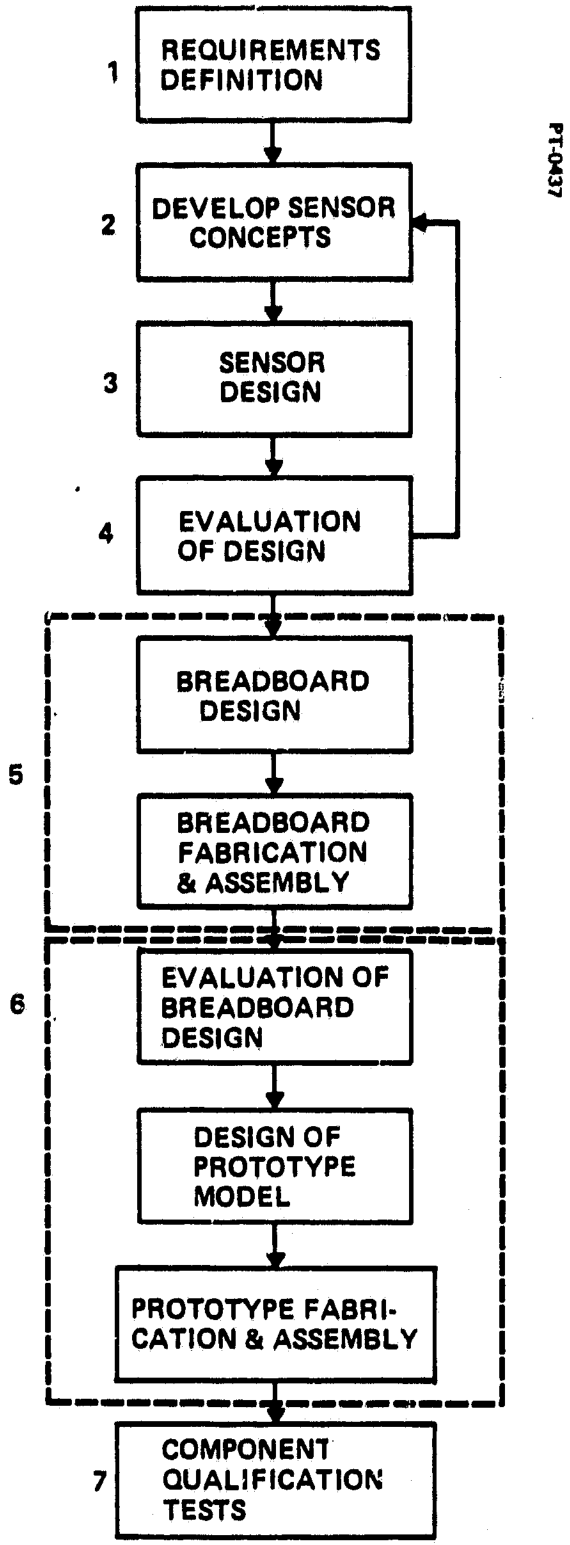

Figure 4.0-1. EC/LSS Sensor Technology Development Flow

Furthermore, the weaknesses defined may require solutions involving such mundane items as calibration of equipment, replenishing fill solutions, and cleaning.

At this point, a design review could be held to determine whether reiteration of Steps 2, 3, and 4 is necessary or that results are satisfactory and ready for breadboard development.

Step 5: Breadboard Design and Fabrication - A laboratory scale sensor, and the associated EC/LSS subsystem they are intended to measure (identified as part of Step 3) could be simulated in a laboratory environment. Breadboard sensors can be assembled in a Water Quality Monitor (WQM) breadboard with appropriate performance measuring instruments. This could permit reevaluation of sensor performance as they interact with other equipment in the WQM unit and to facilitate evolution of the breadboard itself.

Step 6: Evaluate Breadboard - Operation of the breadboard could commence with evaluation tests of sensor accuracy throughout the range of required environments. Because this is the last step before prototype fabrication, any anomalies still remaining would be resolved and a critical design review held.

A detailed design activity could be the next step. The hardware component items and materials to be used in the protoflight model would be flight rated if possible. The accommodation of overall system requirements on the sensor should be input to the design process. In addition, techniques of operating the sensors could be defined that would complement space station configuration and operational characteristics.

Step 7: Component Qualification (Ground-Based) - Tasks could include:

- o extended testing in environmental range
- o autocycling - auto calibration checks
- o functional test in environmental simulator
- o static and dynamic loads testing

4.2.2 Facility Requirements/Candidate Facilities

The facilities required to support the recommended developments include:

(A) Chemical process development and trest laboratory facilities for possible small scale membrane fabrication and testing (technical approach Step 4).

(B) Proof test facilities capable of testing membrane sensor devices, cathode/solution /anode electrical measuring devices, and other measurement techniques for verifying sensor concepts and measuring performance.

(C) Fabrication facilities capable of manufacturing relatively simple EC/LSS subsystem component analogues such as solution baths, cookers, sivs, etc.

An illustrative tabulation of NASA facilities related to the housekeeping technology area are provided in table 4.0-3. MSFC facilities specifically adapted to the development of EC/LSS component sensors are identified with a single asterisk (*). Based on this facility review, no new facilities should be necessary to support the overall expert systems technology program.

4.2.3 Schedules

The major milestone schedule for the development of EC/LSS sensor technology is shown in figure 4.0-2. The estimated time frames for each major development phase are shown. This schedule can support a space station new start in FY86 and will also provide TOC and NH_3 sensor models for EC/LSS and data management system breadboard testing.

4.2.4 Resources

The time phased resource requirements estimate for the EC/LSS sensor development efforts are shown in table 4.0-4.

4.3 OVERALL EXPERT SYSTEMS

Expert systems is a concept that forms part of the more general data processing technique called artificial intelligence. The need for, and method of implementation of expert systems for integrating the automation of housekeeping functions on the space station is dependent on the particular set of sensed data. In any case, a certain amount of human interaction, which is characteristic of expert systems would be needed because the decision making rules could need adjustment as operational experience is gained.

4.3.1 Technical Approach

A large part of this development effort is focused on system definition because of the system level nature of housekeeping control. Beginning with requirements definition,

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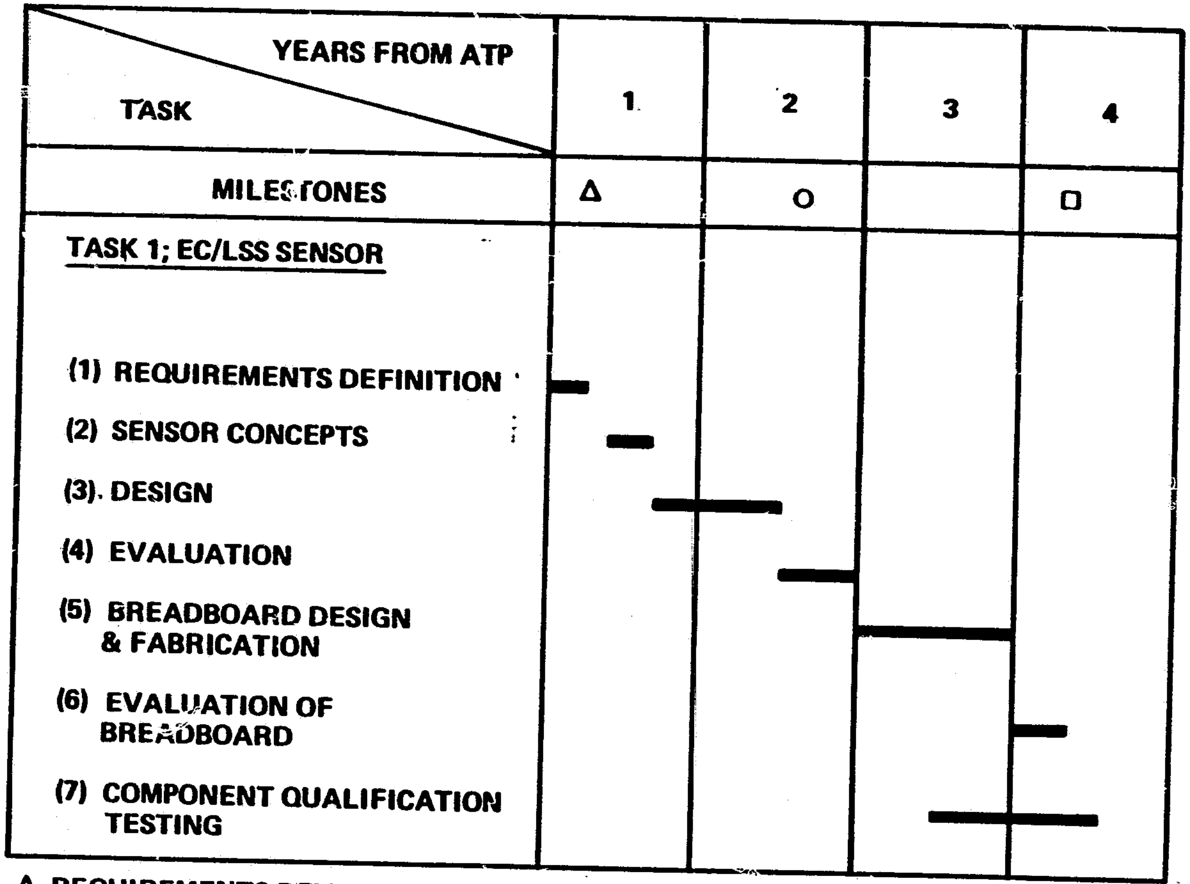

Δ REQUIREMENTS REVIEW   O DESIGN REVIEW   □ FINAL REVIEW

Figure 4.0-2   EC/LSS Sensor Technology Development Schedule

TABLE 4.0-3. FACILITY CANDIDATES FOR INTEGRATED AUTOMATION OF HOUSEKEEPING TECHNOLOGY DEVELOPMENT

ID CODE	NASA CENTER AND FACILITY NAME
	MARSHALL SPACE FLIGHT CENTER
4487-EC-11	*Electronics Lab
4487-EC-12	*Control and Display Lab
4487-EC-14	*Electronics Circuit Development Lab
4487-EC-16	**Microprocessor Applications Laboratory
4487-EC-35	*Electrical Component Development Lab
4659-AC-1	**Univac 1100/82
4659-AC-2	**Univac 1108
4708-AC-1	**IBM 360/75 General Purpose Computer System
4708-EF-8	**Digital Techniques Development Laboratory
4708-EF-11	*Electronic Development Lab's
4708-EF-13	*Data Systems Test and Development Laboratory
4708-EF-14	**Integrated Software Development Facility
4708-EF-20	*Experiment Data Systems Integration Lab
4708-ET-10	*Payloads and Systems Test Laboratory
	AMES RESEARCH CENTER
N-233	**Central Computer Facility
	JOHNSON SPACE CENTER
440	*Communications Component Development Laboratory
440	*Command and Modulation Laboratory
15	**Laboratory, Spacecraft Data Systems
7	*Life Sciences Laboratory Complex
	LANGLEY RESEARCH CENTER
1268	**Data Reduction Center

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Figure 4.0-4. Resource Requirements for Each Sensor Technology Development for a TOC Sensor and an Ammonia Sensor

TASK / YEARS FROM ATP	1	2	3	4	TOTAL	REMARKS
TASK 1: EC/LSS SENSOR						•PRESENT YEAR DOLLARS •FIGURES IN $1000 •SAME FOR TOC & AMMONIA SENSOR
(1) REQUIREMENTS DEFINITION	30	–	–	–	30	
(2) SENSOR CONCEPTS	30	–	–	–	30	
(3) DESIGN	–	80	–	–	80	
(4) EVALUATION	–	20	–	–	20	
(5) BREADBOARD DESIGN & FABRICATION	–	–	120	–	120	
(6) EVALUATION OF BREADBOARD	–	–	–	20	20	
(7) COMPONENT QUALIFICATION TESTING			100	100	200	
TOTAL	60	100	220	120	500	

tasks to identify modes of operation, controller interactions with subsystems, human operators, and crew members and constraints imposed by hardware and software configuration control could be performed. Integration issues of control approach (centralized or decentralized), controller response to transients and load migration, maintenance and repair provisions, and the definition of default priorities in the event of anomalies and failures would be addressed. Upon completion of this task, a requirements review would be held and documented to provide controller specifications such as fault isolation and energy balancing techniques to be used as well as establishment of rules, identification of data items, interacting facility characteristics, and subsystem models for algorithm development. Also during this phase, the portions of the overall expert system controllers which are appropriate could be established.

Once the need for the expert systems controller has been verified, a similar development process for each is proposed. The steps in that process (see figure 4.0-3) and a description of each element follows.

Step 1: Develop a simulator and set of manual controls for the system. This can be done in either hardware or software.

Step 2: Create a suite of scenarios of various conditions to which the system would be subjected. Ideally, the suite should cover all conditions including normal and crisis condition.

Step 3: Train the astronauts to respond to the suite in an acceptable manner. The goal should be to satisfy rather than optimize. The expert systems approach is particularly well suited to subsequent modification as experience is gained; thus, premature optimization should be avoided.

Step 4: Once the astronauts are performing satisfactorily, identify those functions not well suited for closed loop automation. These functions should be incorporated into the Expert Systems level of controllers. The remaining functions should be analyzed to determine what type of closed loop controller is best for each function.

Step 5: Design the Expert Systems type of controllers by soliciting the rules from the astronauts.

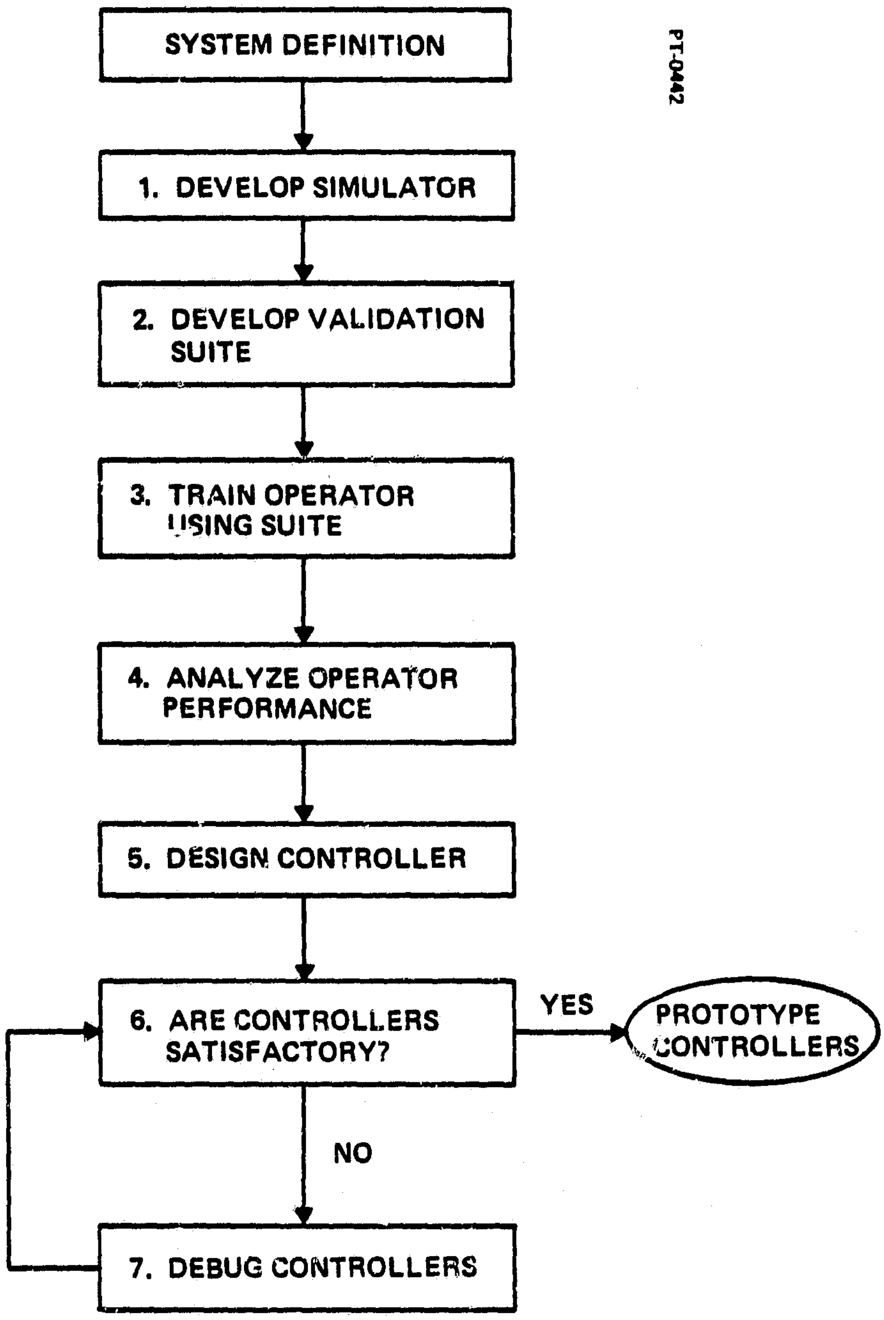

Figure 4.0-3 Expert System Development Flow

Step 6: Validate the controllers using the suite of scenarios. If the controllers are satisfactory, the development process is complete.

Step 7: Debug the rules in conjunction with the astronaut. This step will almost certainly be an iterative process. Expert system architectures are generally designed to facilitate iterative development. Repeat step 6 after debugging the rules.

Finally, the software for the rules and the data base needs to be prepared, verified, validated, and integrated with the data processor hardware and interactive equipment which will be used in the space station. This step is considered part of the space station design activity and is included here for completeness. Furthermore, at this point, it may be preferable to perform a systems evaluation with a data management system simulator to assure compatibility and identify anomalies.

4.3.2 Facility Requirements/Candidate Facilities

Facilities requirements necessary to support the recommended develoment are as follows:

(A) Scientific computer facility to develop subsystem models using CAD techniques and applications programs such as LISP. Also, an interactive work station should be employed to accommodate training of astronauts.

(B) (Optional) The data Management System Simulator. See section 4.2 for details of this facility.

An illustrative tabulation of NASA facilities which have capabilities pertinent to the various technology areas of housekeeping subsystems is provided in table 4.0-3. MSFC facilities specifically applicable to fulfilling the requirements listed above are indicated with two asterisks (**). Other center facilities have some of the same capabilities and could be used. Based on this review, no new facilities should be necessary to support this technology development program.

4.3.3 Schedules

The major milestone schedules for the development of overall expert system technology are shown in figure 4.0-4. Shown are the estimated time frames for each major development phase. This schedule would not support a Space Station new start in FY86

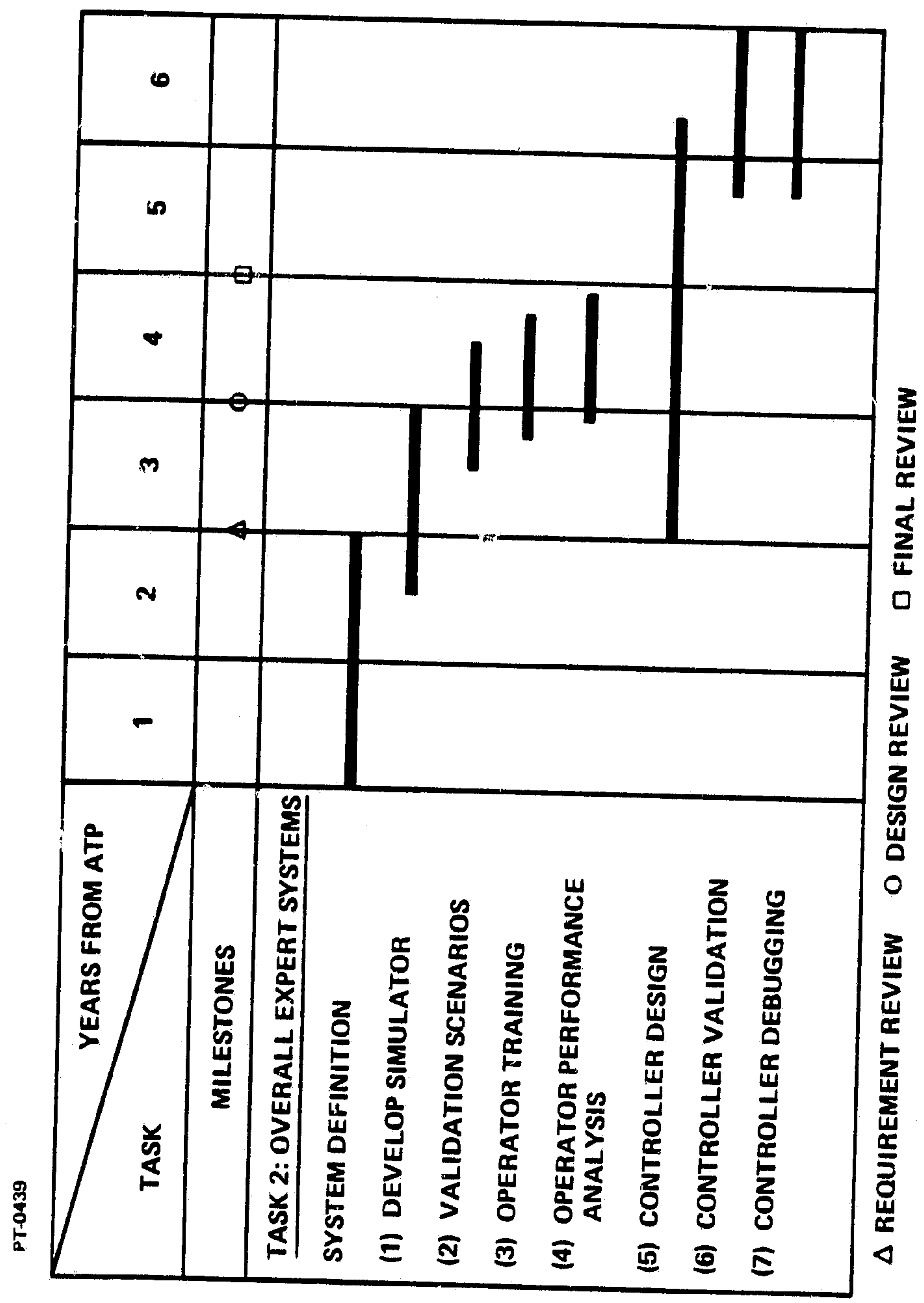

Figure 4.0-4 Overall Expert System Technology Development Schedule

but would provide expert controller models for power, thermal, and EC/LSS to support an early evolution of the manned space station in the mid-1990's.

4.3.4 Resources

The time phased resource requirements estimates for the overall expert systems development effort are shown in table 4.0-5. The number of applications suitable for expert controllers on the space platform will significantly affect cost. The estimates presented are based on a nominal requirement for three subsystem controller developments. It is assumed there is no difference in the ROM cost for centralized or distributed controller architecture since the algorithms must be developed in either case.

PT-0435

Table 4.0-5 Resource Requirements for Advancement of Expert Systems for Application to Integration Management of Automated Housekeeping Subsystems

TASK \ YEAR FROM ATP	1	2	3	4	5	6	TOTAL
FIGURES IN $1000							
SYSTEM DEFINITION	500	600					1100
1) DEVELOP SIMULATOR		500	1000				1500
2) VALIDATE SENARIOS			500	500			1000
3) OPERATOR TRAINING			100	100			200
4) OPERATOR PERFORM-ANCE ANAYLSIS			100	100			200
5) CONTROLLER DESIGN			500	1000	500	500	2500
6) CONTROLLER VALIDA-TION					750	750	1500
7) CONTROLLER DEBUG-GING					500	500	1000
TOTAL	500	1100	2200	1700	1750	1750	9000

5.0 LONG LIFE THERMAL MANAGEMENT SYSTEM TECHNOLOGY ADVANCEMENT PLAN

5.1 INTRODUCTION

Various technology advancements are needed to meet thermal management technology goals as summarized in table 5.0-1. Life requirements of up to 20 years is a major concern of thermal management technology. The primary life limiting factor is degradation of thermal coatings on the space radiators. A number of thermal coatings have been developed and used on various spacecraft; however, they have all been subject to degradation due to radiation and/or surface contamination. An on-going NASA program is being conducted to develop techniques to maintain coating surface properties for indefinite lifetimes. Trade studies, reported in Volume II, investigated alternative methods of alleviating the coating degradation problem. These studies identified the following areas as offering the greatest benefits from technology development:

1) Thermal Storage
   a) Pumped Liquid Loop
   b) Two Phase Heat Transport
2) Steerable Radiators

These areas are, by no means, the aggregate of long life thermal management system technology advancement requirements. However, they are the most critical near term areas as defined by the system level trades. Furthermore, a review of the FY82 RTOP activities, shown in table 5.0-2, indicate that activities in the selected areas identified by this study are justified for increased emphasis. It is recognized that these developments are at the component or subsystem level and it is likely that thermal management system performance verification at the systems level will be necessary. This will require a system breadboard for which these developments could be an integral part.

5.2 THERMAL STORAGE

5.2.1 Descritpion/Benefits

A thermal storage device effectively stores and transfers thermal energy at a specified temperature for minimizing peak loading conditions. System level trades conducted during this study show that a lightweight efficient thermal storage device offers the

Table 5.0-1 *Time Phasing of Long Life Thermal Management Advancement Goals*

PT-0478

TIME PHASE	NEAR TERM	EXTENDED
EVOLUTION	BASIC MANNED PLATFORM	EVOLUTIONARY MANNED PLATFORMS
HEAT LOAD CAPACITY	100 KW	250/500 KW
ORBITAL ENVIRONMENT	LEO	LEO/GEO
TRANSPORT DISTANCE	150 FT	150–300 FT
LIFE	> 20–25 YRS	SAME
CONFIGURATION GROWTH	MODULAR/ASSEMBLY	MODULAR/CONSTRUCTION
RESUPPLY GOALS	OPTIMIZED BASED ON CURRENT AND NEAR-TERM TECHNOLOGY	25 TO 50% IMPROVEMENT BASED ON NEAR-TERM REQUIREMENTS
MAINTAINABILITY	ON-ORBIT REHABILITATION AND REPAIR AS REQUIRED TO MEET LIFE REQUIREMENTS	SAME

TABLE 5.0-.2 1982 RTOP SUBMISSIONS RELATED TO LONG LIFE THERMAL MANAGEMENT FOR SPACE STATION APPLICATION

CENTER	TITLE	OBJECTIVES	BENEFITS
JSC	Thermal Management For on-orbit energy systems	o Develop large space power system thermal management technology o Extended orbital lifetime capability o Provide tech. for high energy density heat collection and transport o Reduce cost of large scale system o Design, development, fabrication, and test of prototype hardware	o Extended life of system, reduced cost
LaRC	Analysis and Design	o Develop integrated multi-disciplinary (structural/thermal) analysis and synthesis methodology with some effort focused on large space structures	o Improved structural heat transfer o Development of an integrated structural/thermal analysis capability
MSFC	Thermal Protection System	o Component, design, fabrication, and testing of components vital to future thermal control systems o System breadload evaluations	o Understanding of system performance and life characteristics of new generation TCS for space platform-type applications

potential for vastly reducing the surface (weight) requirements of the Space Station Radiator (See Volume II). The thermal storage device flown on Skylab interfaced with the air lock radiator/fluid loop and was designed to meet a heat rejection requirement on the order of 0.5 kWH. A similar device for space station will be considerably larger and require well over an order of magnitude larger storage capability. This will magnify packaging, control, and heat distribution problems in the larger storage device. The goal of this development is to demonstrate, through proof-of-concept tests, a viable thermal storage device design that can be developed at minimum risk for the early space station.

5.2.2 Technical Approach

Since the Space Station thermal management system definition is not currently at a level sufficient to define the specific thermal storage device interfaces, parallel development paths are followed for thermal storage integration with a two phase heat thransport system and a pumped liquid loop system. This provides flexibility for interfacing with either heat transport system and allows the technology to proceed in a time frame compatible with a FY86 start. Development of a thermal storage device that has an interface with a two phase heat transport loop is more difficult and costly, especially in the interface design and verification testing. Therefore, the two designs (i.e., pumped loop, two phase) have been scheduled and costed separately to provide improved visibility for time and resource requirements. Since the majority of the development activities are similar, they are combined in the logic flow as shown in figure 5.0-1. The major activities are identified and grouped as shown, by the dashed border, and the activities of each group are described below:

Step 1 - Packaging concepts can be developed for each interface design. This will establish overall envelopes, preliminary interface requirements and internal configurations.

Step 2 - Thermal storage materials can be evaluated and candidate materials selected based on characteristics such as storage capacity, materials compatibility, volumetric expansion, thermal diffusion, long term stability, and compatibility of phase change material with control requirements.

Step 3 - Selected materials can be integrated with viable packaging concepts and design trades conducted to select the most viable designs for further development. At this time, test plans identifying objectives, test requirements, instrumentation requirements, facility

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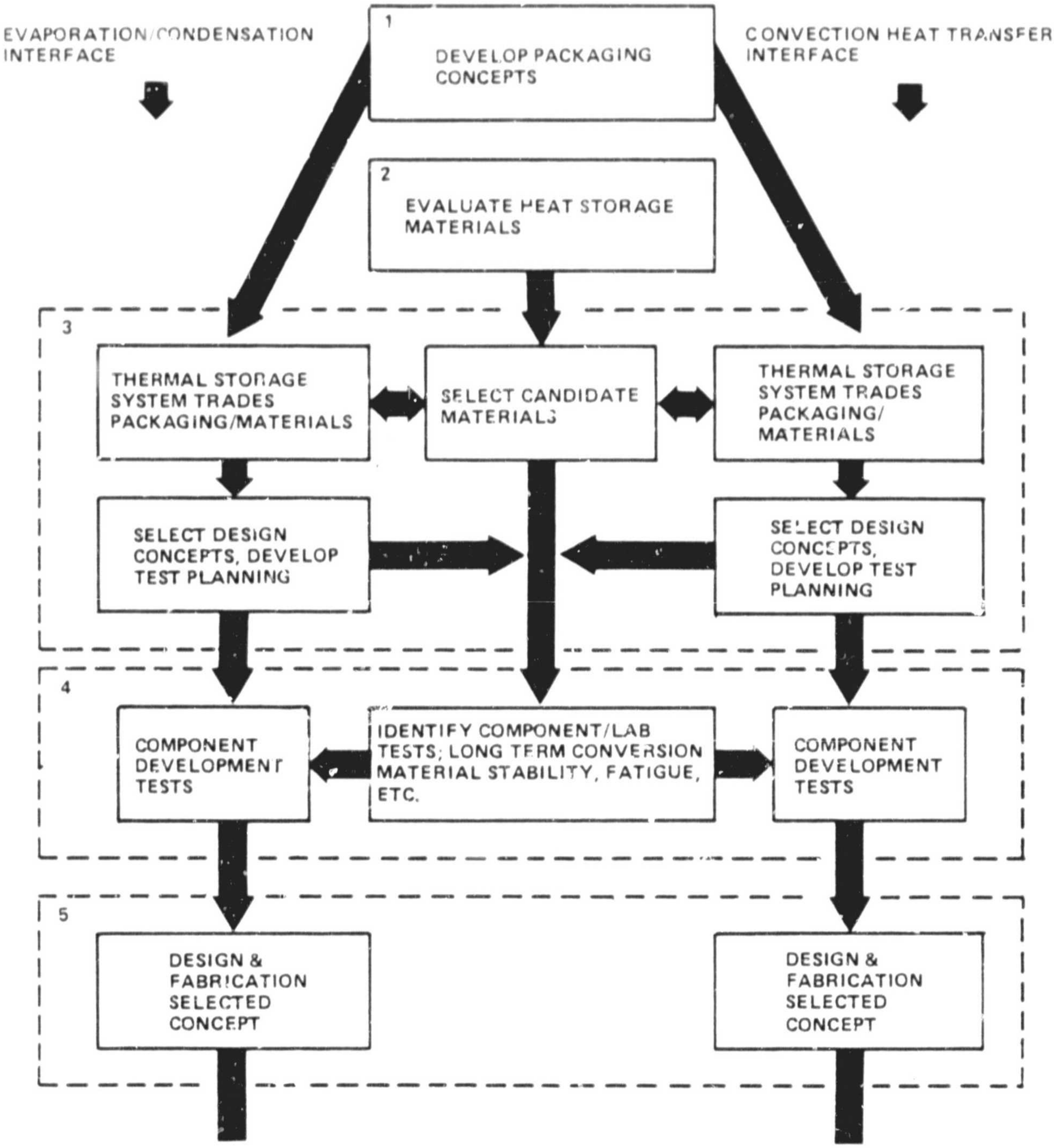

Figure 5.0-1 Thermal Storage Technology Development

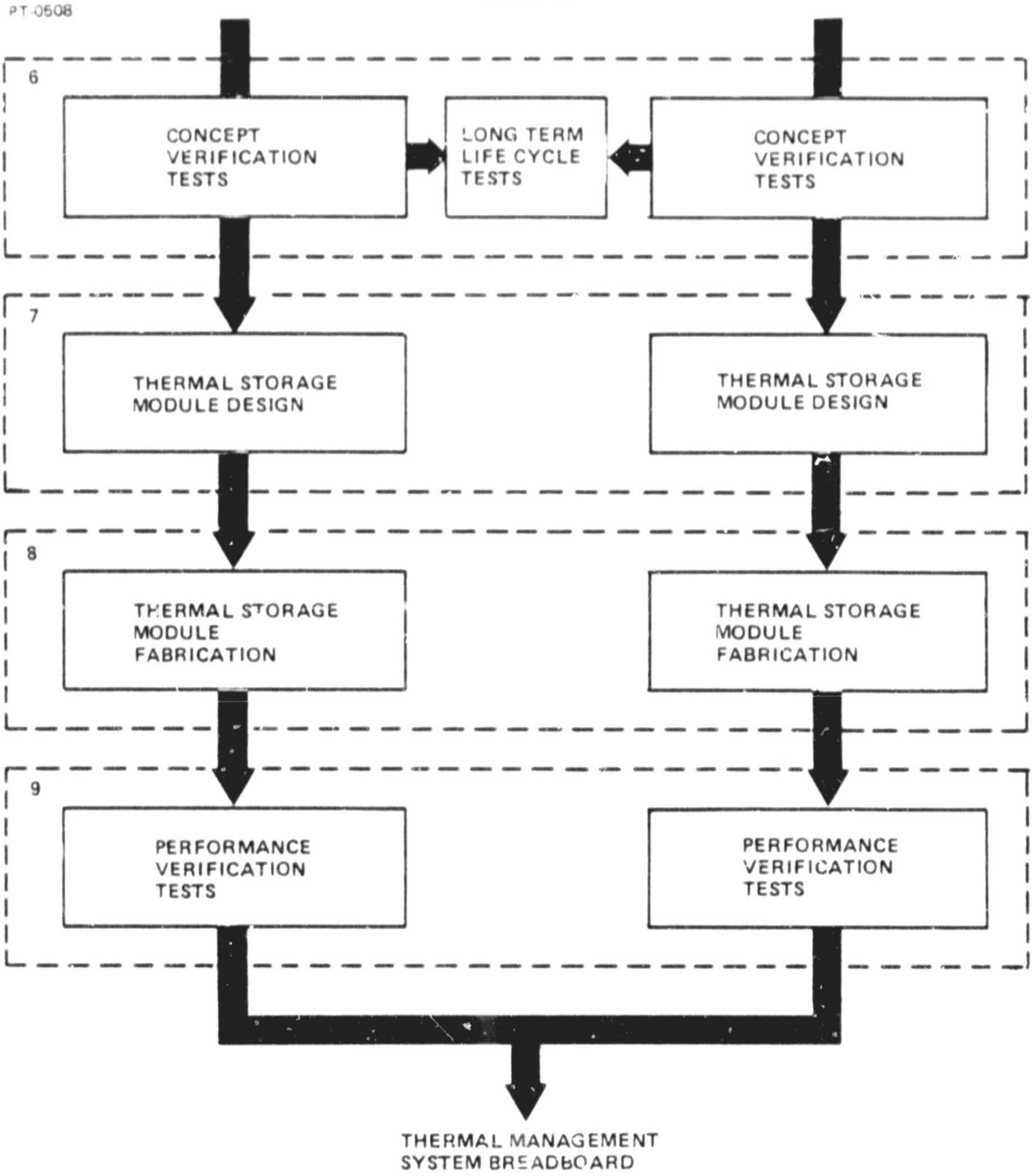

Figure 5.0-1 Thermal Storage Technology Development (Cont'd)

and special test hardware requirements will be initiated for both the pumped loop and two phase interface designs. This planning can be time phased to support the design and testing activities.

Step 4 - Basic laboratory tests which may be necessary to define such characteristics as long term materials compatibility and/or corrosion effects, chemical stability of phase change material to long term thermal cycling, material fatigue, etc., can be identified and tests conducted as required, to suport the design of the selected concepts.

Step 5 - Test articles representing the selected concepts can be designed and fabricated. These could be small scale test sections that represent the critical design characteristics of the full scale module such as thermal response, thermal conduction paths, and long term performance stability and tests to investigate possible adverse gravity effects on the two phase interface.

Step 6 - Tests can be performed on these test sections to evaluate and verify the concept performance. Long term life cycle tests will be conducted to determine performance stability and/or degradation over long periods of operation, and many thermal cycles.

Step 7 - Based on the previously acquired test experience, a thermal storage module design can be developed. This design should be representative of modules that can be combined to build up the full scale space station thermal storage device.

Step 8 - Following the design phase, the modules can be fabricated, including the installation of all necessary instrumentation.

Step 9 - Testing can follow to verify module performance. These tests will simulate space statio cyclic heat loads and interface requirements. The test hardware can be available for system level tests in a thermal management system breadboard following the verification testing.

5.2.3 Facility Requirements/Candidate Facilities

Facilities requirements necessary to support the recommended development are as follows:

(A) Materials testing and evaluation laboratory facilities to determine material properties, compatibility, corrosion, and stability over long term thermal cycling.

(B) Proof test facilities and facilities capable of testing flow devices such as heat exchanges for thermal performance, flow distribution and pressure losses. This facility should also be capable of handling two phase flow and instrumentation capable of determining flow quality should be available. Special instrumentation/techniques are required to determine the solid/liquid interface location as the phase change material melts and freezes.

(C) Fabrication facilities capable of fabricating relatively complex components such as extended surface heat exchangers, and clean room accommodations for component assembly.

A tabulation of NASA facilities is provided in table 5.0-3. MSFC facilities specifically applicable to development, fabrication and testing of a thermal storage device are identified by an asterisk (*). Other center facilities have some of the same capabilities and could be used. Based on this facility review, no new facilities should be necessary to support the thermal storage technology program.

5.2.4 Schedules

The major milestone schdules for both development paths of the long life thermal storage devices are shown in figures 5.0-2 and 5.0-3. Shown are the estimated time frames for each major development phase. This schedule identifies the near term developments and should not be interpreted as total requirements for a far term space station. The advanced station technology will grow from these early developments which are necessary for both the near and far term stations. Assuming an FY84 start, this schedule support a space station start in FY86 and will also provide a thermal storage module for thermal management system breadboard testing.

TABLE 5.0-3. FACILITY CANDIDATES FOR LONG-LIFE THERMAL MANAGEMENT TECHNOLOGY DEVELOPMENT

ID CODE	NASA CENTER AND FACILITY NAME
	JOHNSON SPACE CENTER
13	Systems Evaluation Laboratory
15	Environmental Test and Evaluation Laboratory
32	Space Environment Simulation Chamber B
33	Space Environment Effects Laboratory
351	Thermal Vacuum Test Facility
356	Fluid System Test Facility
	MARSHALL SPACE FLIGHT CENTER
4476-ET-1	**Thermal Vacuum Laboratory
4476-ET-9	**Environmental Test Laboratory
4487-EC-21	***Thermal Instrumentation Development Laboratory
4557-ET-2	**Thermal Vacuum Chamber Facility
4605-EH-28	*Nondestructive Materials Evaluation Facility
4612-EH-2	**Ceramics and Coatings Development and Evaluation Laboratory
4612-EH-4	***Composite Materials, Adhesives, and Cryogenic Insulation Developmental and Evaluation Laboratories
4612-EH-5	***Chemistry Diagnostics Laboratory
4612-EH-20	*Corrosion Protection and Control Laboratory
4612-EH-22	*Thermal Processing Facility
4619-ET-7	**Vacuum Chamber (Sunspot I)
4699-ET-1	*Structural Thermal Test Facility
4708-ET-6	*Mechanical Test Laboratory
4711-EH-7	**Adhesive Technology Laboratory
4711-EH-9	*Welding and Brazing Development Laboratory
	LANGLEY RESEARCH CENTER
1148	Structure and Materials Research Laboratory
1205	Fatigue Research Laboratory
	LEWIS RESEARCH CENTER
1111, 1112, 1121, 1131-1136, 1141, 1142, 1151-1157, 1161, 1191-1196	Nuclear Test Reactor Facility
	Thermal Storage Long Life Thermal Coatings Steerable Radiator

TABLE 5.0-3. FACILITY CANDIDATES FOR LONG-LIFE THERMAL MANAGEMENT TECHNOLOGY DEVELOPMENT (Continued)

ID CODE	NASA CENTER AND FACILITY NAME
	GODDARD SPACE FLIGHT CENTER
4	Electrostatic Dust Particle Accelerator
M3	Spacecraft Magnetic Test Facility
4	Thermal Vacuum Solar Simulation Facility
22	Radiation Environment Simulation Facility
22	Propulsion and Environment Test Facility
243, 244, 245	2'x2' Environmental Simulators (3)
237, 239	7'x8' Environmental Simulators (2)
238	12'x15' Thermal Vacuum Chamber
290	28'x40' Space Environment Simulator
2	Ultraviolet Plasma Facility
	JET PROPULSION LABORATORY
158	Material Research Process Laboratory
144	Environmental Testing Laboratory, Natural Environment: Thermal-Vacuum Laboratory
144	Thermal Vacuum Chamber, 7'x14'
248	10' Space Simulator
150	25' Space Simulator

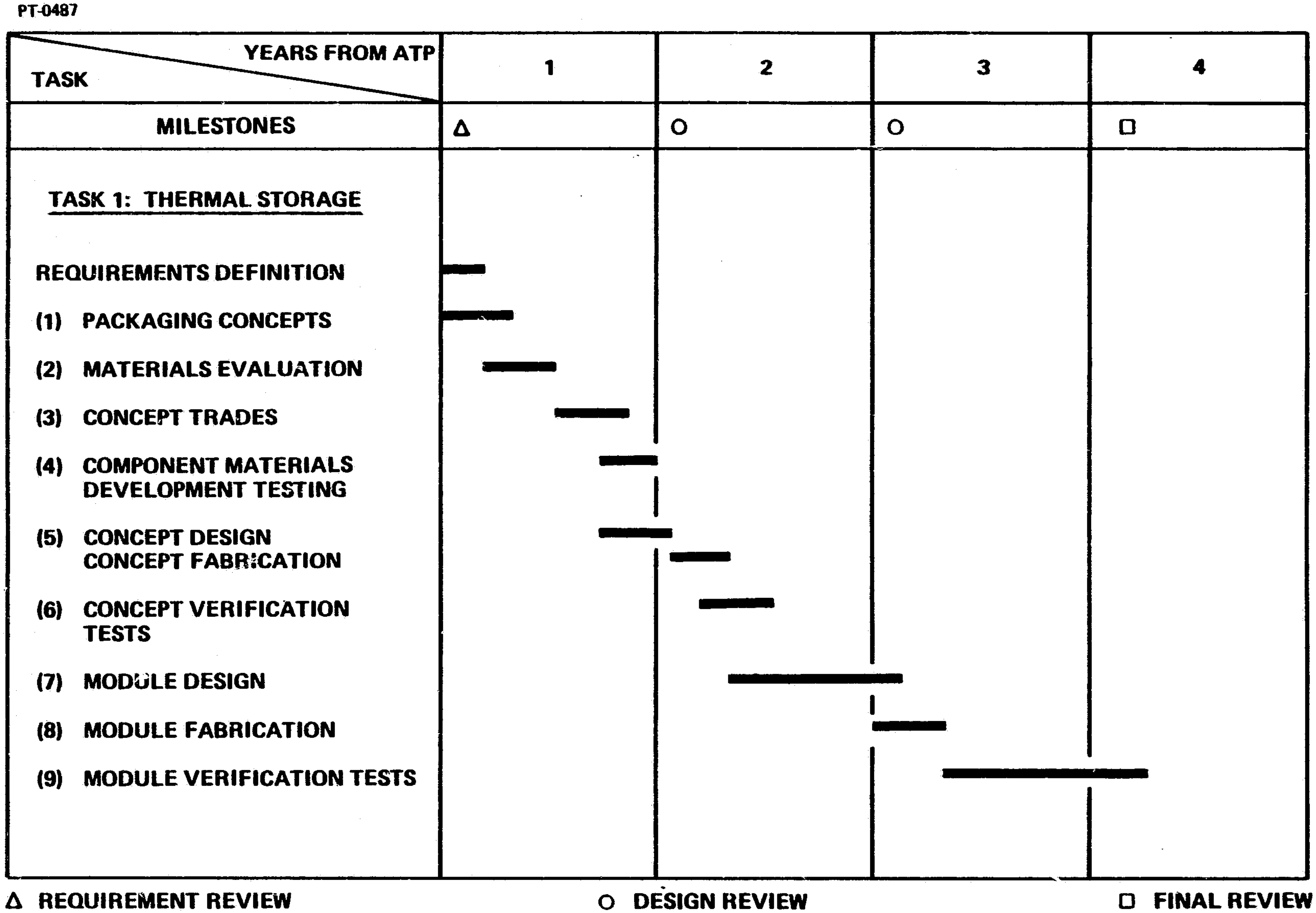

Figure 5.0-2 Long Life Thermal Storage Technology Development Schedule (Pumped Liquid System)

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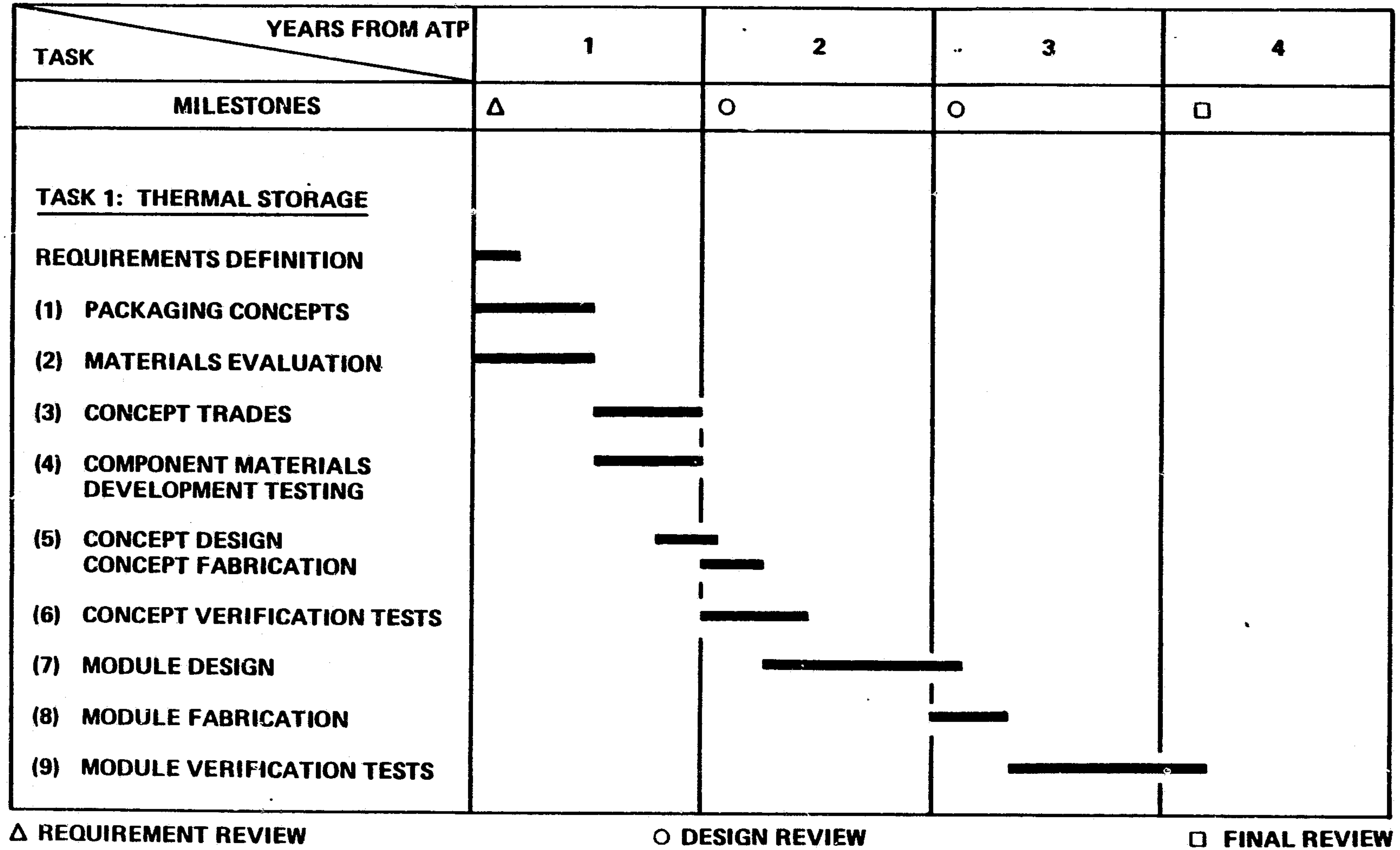

Figure 5.0-3 Long Life Thermal Storage Technology Development Schedule (Two-Phased Transport System)

5.2.5 Resources

The time phased resource estimates for both development paths for the thermal storage development effort are shown in tables 5.0-4 and 5.0-5.

5.3 STEERABLE RADIATORS

5.3.1 Description/Benefits

A steerable radiator effectively avoids a large percent of the solar and infrared heat sources normally seen by fixed radiator systems. This can be accomplished by sensing these environments and steering the radiator to minimize its view to these environments. The advantages to providing this capability are: (1) the radiator can be significantly smaller and lighter, (2) radiator performance is significantly less sensitive to thermal coating degradation, and (3) the potential interference with other subsystems such as solar arrays, blockage of experiment views, etc. is minimized. Table 3.4-2 of Volume II specifically identifies the system weight benefits to be realized from a steerable radiator. Figure 3.4-14 of Volume II also shows the relative insensitivity of the steerable radiator area to coating degradation. The steerable radiator also requires significantly smaller and lighter thermal storage device, which could reduce the technical complexity and cost of storage device development and integration.

5.3.2 Technical Approach

The critical components in a steerable radiator system are the fluid coupling, the steering mechanism, and the environment sensor and controls which must be integrated with the steering mechanism. The develoment approach is indicated in figure 5.0-4. Following is a descritpion of the major development tasks:

Step 1 - Radiator design concepts will be developed to the level necessary to drive out the structural, fluid, and thermal requirements for the fluid coupling and radiator drive mechanism and control.

Step 2 - A radiator concept will be selected to focus the design of a steerable radiator test article. As shown, this will support the component design and the test article design (BLOCK 7).

Step 3 - Based on requirements generated in 1 and 2 above, concepts for fluid couplings and drive mechanisms will be developed and evaluated. As shown, these will include flex

PT-0490

Table 5.0-4 Resource Requirements for Long Life Thermal Storage Technology Development (Pumped Liquid System)

TASK / YEAR FROM ATP	1	2	3	4	TOTAL	REMARKS
TASK 1: THERMAL STORAGE						• PRESENT YEAR DOLLARS • COSTS IN $K
REQUIREMENTS DEFINITION	5	—	—	—	5	
(1) PACKAGING CONCEPTS	15	—	—	—	15	
(2) MATERIALS EVALUATION	10	—	—	—	10	
(3) CONCEPT TRADES	50	—	—	—	50	
(4) COMPONENT MATERIALS DEVELOPMENT TESTING	20	—	—	—	20	
(5) CONCEPT DESIGN	50	50	—	—	100	
CONCEPT FABRICATION	—	50	—	—	50	
(6) CONCEPT VERIFICATION TESTS	—	50	—	—	50	
(7) MODULE DESIGN	—	100	50	—	150	
(8) MODULE FABRICATION	—	—	150	—	150	
(9) MODULE VERIFICATION TESTING	—	—	100	100	200	
TOTAL	150	250	300	100	800	

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Table 5.0-5 *Resource Requirements for Long Life Thermal Storage Technology Development (Two-Phased)*

TASK / YEAR FROM ATP	1	2	3	4	TOTAL	REMARKS
TASK 1: THERMAL STORAGE						• PRESENT YEAR DOLLARS • COSTS IN $K
REQUIREMENTS DEFINITION	5	—	—	—	5	
(1) PACKAGING CONCEPTS	20	—	—	—	20	
(2) MATERIALS EVALUATION	20	—	—	—	20	
(3) CONCEPT TRADES	100	—	—	—	100	
(4) COMPONENT MATERIALS DEVELOPMENT TESTING	60	—	—	—	60	
(5) CONCEPT DESIGN	100	100	—	—	200	
CONCEPT FABRICATION	—	100	—	—	100	
(6) CONCEPT VERIFICATION TESTS	—	100	—	—	100	
(7) MODULE DESIGN	—	100	45	—	145	
(8) MODULE FABRICATION	—	—	200	—	200	
(9) MODULE VERIFICATION TESTING	—	—	150	100	250	
TOTAL	305	400	395	100	1200	

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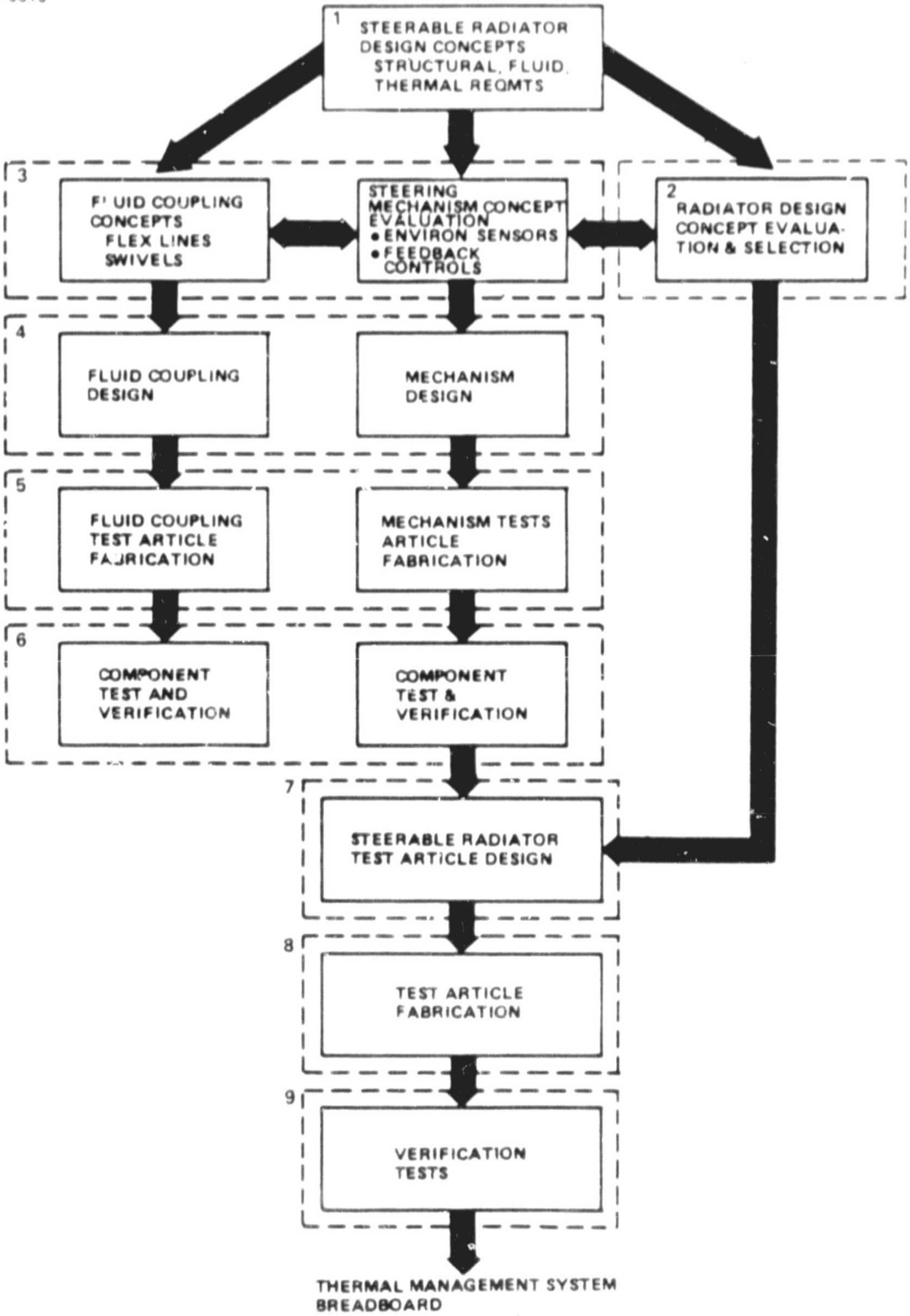

Figure 5.0-4 Steerable Radiator

lines and swivels for fluid transfer at the radiator/support structure interface, and steering mechanism concepts will include the sensors, power sources, and controls.

Step 4 - The fluid coupling and steering mechanism component test article designs will proceed in parallel as shown. These designs will detail the concepts selected in 3. Experience in design of solar array steering mechanisms and controls will be used where appropriate. Component test plans including requirements and instrumentation will be developed.

Step 5 - The test hardware will be fabricated and required instrumentation installed.

Step 6 - Component verification tests such as proof leak and continuity will be performed. Functional operation will be verified in simulated space environments (vacuum, temperature, etc.).

Step 7 - A steerable radiator test article will be designed to provide an integrated test article for the components developed and verified in the above activities. Test plans, including instrumentation requirements, will be developed for verification testing.

Step 8 - The steerable radiator test article will be fabricated, including the installation of all instrumentation.

Step 9 - Testing will be performed on the integrated system to verify operation in a simulated space environment. Following verification, the radiator test article will be available for systems level testing in a thermal management system breadboard.

5.3.3 Facilities Requirements/Candidate Facilities

Facilities necessary to support the proposed developments are as follows:

(A) Facilities capable of performing structural and thermal tests on complex mechanisms. Evaluation of sliding friction and dry film lubrication in a vacuum environment and evaluation of wear rates of sliding and/or rotating surfaces. Mechanical, vibration, and acoustic testing of complex mechanisms.

(B) Materials laboratory to evaluate maerials compatibility of seals and flex hoses to potentially corrosive fluids such as ammonia.

(C) Facilities capable of structural proof testing, and evaluating flow systems such as flow distribution, fluid pressure loss, and seal leak rates.

(D) Space Environmental Simulators capable of accommodating a representative radiator panel for performance simulation. The capability to evaluate drive mechanism and environment sensor requires solar and infrared source simulation.

(E) Manufacturing facilities capable of fabrication and assembly of complex mechanisms, and leak tight rotating seals. Clean room facility for component assembly.

The MSFC facilities in table 5.0-3 specifically applicable to the above requirements are indicated by three asterisks (***). Other center facilities have similar capabilities and could be used. No new facilities should be required to support advancement of the steerable radiator technology.

5.3.4 Schedules

The major milestone schedule for development and verification of a steerable radiator system is shown in figure 5.0-5. Shown is the estimated time for each development phase. these are development tasks to support the early space station. The far term station will require further technology advancements to improve performance of these components in terms of long life, reliability, reduced cost, risk, and weight. Assuming a FY84 start, this schedule will support a space station start in FY86, and will provide a steerable radiator test article for integration into a thermal management system breadboard.

5.3.5 Resources

The time phased resource requirements estimates for this development are shown in table 5.0-6.

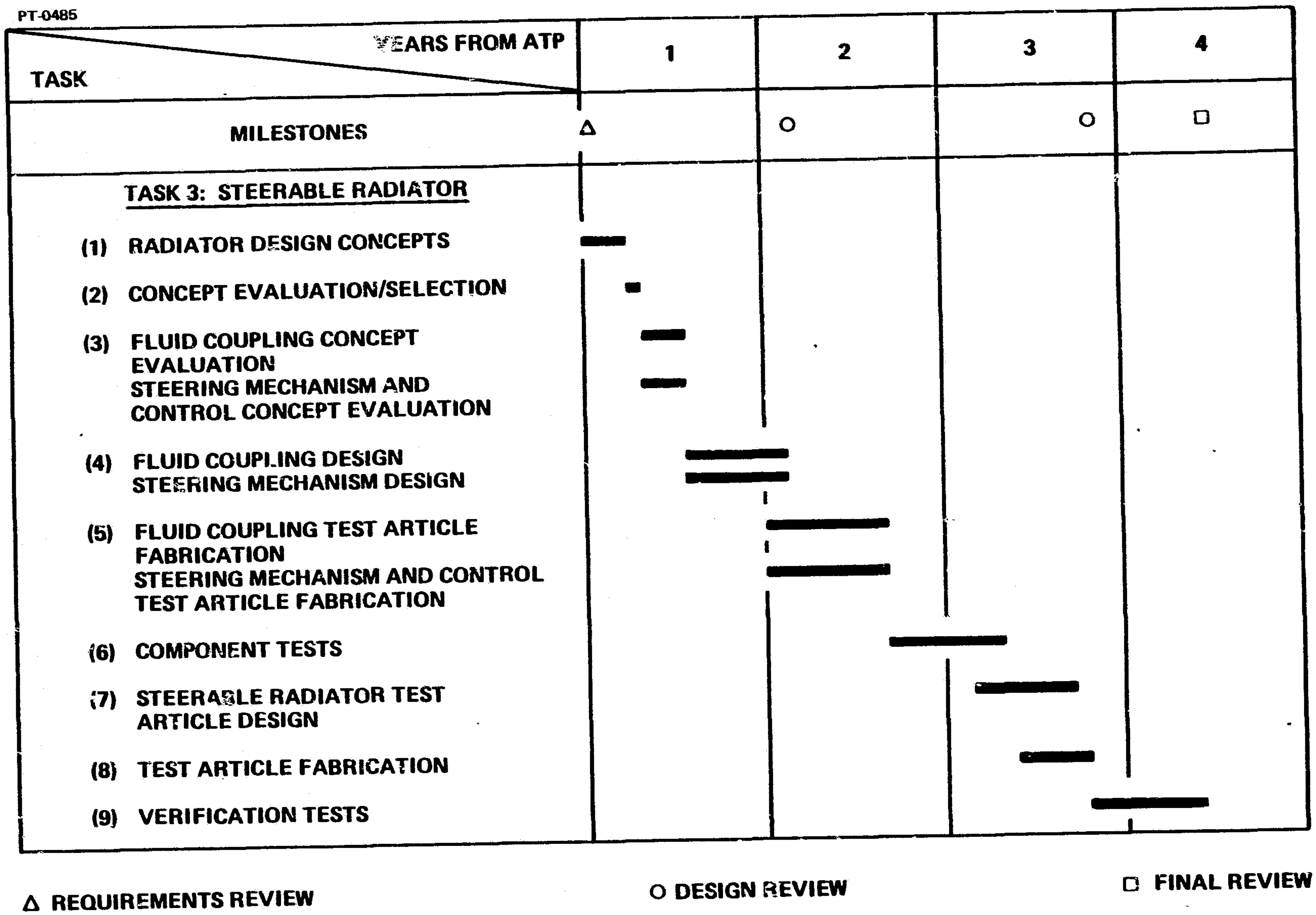

Figure 5.0-5. Steerable Radiator Technology Development Schedule

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Table 5.0-6 Resource Requirements for Steerable Radiator Technology Development (Fluid Coupling)

TASK / YEARS FROM ATP	1	2	3	4	TOTAL	REMARKS
TASK 3: STEERABLE RADIATOR						• PRESENT YEAR DOLLARS • COSTS IN $K
(1) RADIATOR DESIGN CONCEPTS	100	—	—	—	100	
(2) CONCEPT EVALUATION/ SELECTION	30	—	—	—	30	
(3) FLUID COUPLING CONCEPT EVALUATION	70	—	—	—	70	
(4) FLUID COUPLING DESIGN	100	150	—	—	250	
(5) FLUID COUPLING TEST ARTICLE FABRICATION	—	150	—	—	150	
(6) COMPONENT TESTS	—	100	50	—	150	
(7) STEERABLE RADIATOR TEST ARTICLE DESIGN	—	—	50	—	50	
(8) TEST ARTICLE FAB	—	—	200	—	200	
(9) VERIFICATION TESTS	—	—	200	400	600	
TOTAL	300	400	500	400	1600	